Lightweight Bonded Mirror Structures

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Executive Summary

We are investigating alternate methods of reducing the weight of mirrors for space applications while maintaining the required stability of surface form.

Two alternate means of joining Zerodur® components without epoxy will be investigated and the optimum method will be chosen for use in the second half of the project. Epoxy is to be avoided mainly because of thermal expansion issues.

Once the preferred bonding method is selected a couple of lightweighted 150mm diameter planar mirrors will be made to different designs.

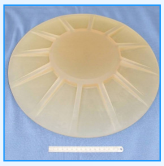
The first design planned is to bond a planar back plate onto a traditionally pocketed mirror blank. This increases the stiffness, allowing a thinner overall substrate to be used, without compromising the weight excessively. The second design will use smaller individual components bonded together to yield significant lightweighting fractions. This offers significant cost savings in both manufacture and launching fees, but at significantly higher technical risk.

The project started at the end of May 2012 and will run for 9 months.

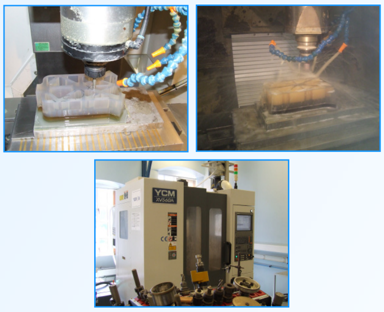
Traditional Lightweighting

Mirrors that are manufactured for space applications are made lightweight to reduce the cost of launching the payload. Typically the blank is machined out of solid with diamond tools on a CNC milling machine prior to final polishing. The process is both time consuming and risky. As the webs are made thinner to reduce weight the chances of damage to the substrate increases significantly. Webs must be of the order of 3 to 5mm thick typically. In addition, all corners need to be rounded to reduce the probability of stress caused flaws.

Typical satellite image using lightweight mirror



Reverse side of a lightweighted mirror



Machining a lightweighted mirror

WP1 – Bond Trials

There are a variety of methods of bonding materials together. The materials of interest in this project are Zerodur® manufactured by Schott, and ULE® manufactured by Corning. Both exhibit extremely low coefficients of thermal expansion (CTE) (<0.1ppm/℃)

Epoxy cementing is common in many applications but is not desirable because the high CTE will distort the mirror. In addition material choice is limited due to stringent outgassing requirements.

When two polished clean surfaces are pressed together optical contacting occurs. While offering excellent levels of alignment accuracy the bonds can be broken by either thermal or mechanical shock.

Other permanent methods of bonding including using low temperature glass frit, and cold metal bonding.

In this project the first method that will be investigated is diffusion bonding. Optical contacted surfaces are treated at high temperature (400 – 700℃) to make the bond permanent. However Zerodur has a maximum service temperature of 450℃ before permanent changes to its CTE are observed.

The second method is to use adhesive free bonding, where surfaces are activated prior to joining, and chemical bonds form permanently between the two surfaces. This is a low temperature process (<100℃) suited to many materials.

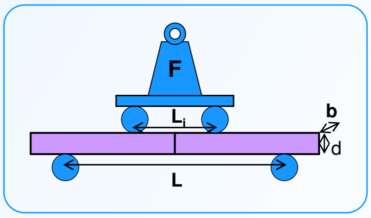
Strength Testing

In order to evaluate the various bonding processes flexural strength testing will be used. Care is required to ensure any strength test yields repeatable and reliable results. Test pieces will be bonded by various methods and subjected to a four point bending test, as is common [1,2].

4 point bend test rig

[1] R. T. Fenner. Mechanics of Solids. CRC Press, 1993.

[2] ASTM C1161-02c, Standard Test Method for Flexural Strength of Advanced Ceramics at Ambient Temperature. ASTM International, 2008.



3 pt bend test $\sigma = \frac{3FL}{2bd^2}$

4 pt test Li = L/3 $\sigma = \frac{FL}{bd^2}$

4 pt test Li = L/2 $\sigma = \frac{3FL}{4bd^2}$

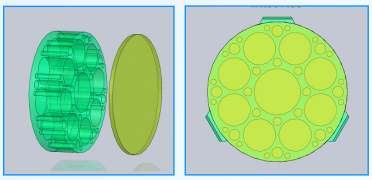
4 pt test General case $\sigma = \frac{3F(L - L_i)}{2bd^2}$

σ = Flexural Strength
F = load at break point
L = length of support span
b = width of beam
d = thickness of beam
L_i = length of loading span

WP2 – Bonded Mirror

The target component is a plano mirror, diameter 150mm, with mounting features. In the original proposal we planned to pocket the bulk of the mirror from one piece of material more aggressively than traditional lightweighting and then attach a thin sheet to the open side to stabilise the part. However for manufacturability it is significantly quicker and less risky to drill holes completely through the core and then attach two thin sheets. This is the design that will be fabricated for WP2.

The bonding method for the face plates will be decided on the basis of the results of WP1. The final operations are to polish and coat the mirror surface ready for environmental testing. Breather holes will be incorporated into the design for vacuum compatibility.



Original and current design for WP2 mirror

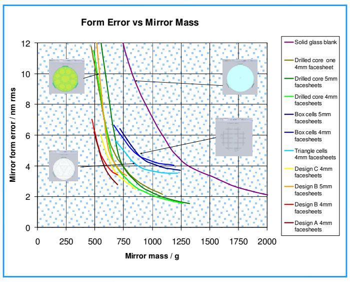
WP3 – Bonded Mirror #2

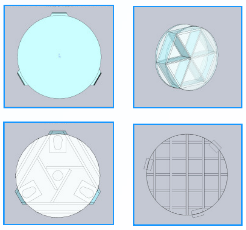
A number of alternative designs have been investigated for both performance vs weight, and manufacturability. FEM modelling was carried out for each option with deflection under a 1g static load vs mirror mass the key performance parameter. Higher mass is achieved by increasing the thickness of the mirror core. Both 4mm and 5mm thick face sheets were modelled.

Initially a solid mirror was modelled as the worst case scenario (pink line, top right of graph). WP2's design of a drilled core with two face plates turns out to have excellent performance which is difficult to improve upon (orange and yellow lines).

Various cores constructed from thin strips of material were tried. While offering excellent usage of material the performance is disappointing and the completed design is suspected to be challenging to manufacture. These designs have been discarded.

One design does offer improved performance over the drilled core and is also suitable for manufacture. This will be fabricated and assembled as WP3 of the project.





Models for the design of WP3 bonded mirror Ø150mm

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