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Synopsis of :

Structural adhesives for bonding optics to metals: a study of opto-mechanical stability

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This paper emphasizes the importance of the adhesive choice for bonding glass to metal and also points out that instant UV-curing adhesive can substitute traditional epoxy. There are many adhesive properties that should be taken into an account before final choice of the epoxy: coefficient of thermal expansion (CTE), thermal conductivity, shrinkage during curing, viscosity, cure temperature, outgassing, module of elasticity and ultimate strength. With the variety of choice of the adhesives it is not clear which epoxy would provide a better performance. Using the wrong epoxy may lead to the failure of the system, which is very costly sometimes. Authors in this paper study the optomechanical properties of the glass-aluminum bond for three different epoxies and three glasses. Analysis was performed for five different bond configurations: (1) a flat plate, (2) three raised in-plane pads, (3) a counter-bored recessed cell with a through hole, (4) a counter-bored opening with a through hole and side holes for injected edge bonding and (5) a flexure designed mount.

Adhesives are usually labeled as 2-part, 1-part, RTV, UV-cure, etc. UV-curing epoxy originally was made for bonding glass to glass and it is transparent. Two optical elements with matching surface curvature can be aligned to each other and then UV light is used to permanently fix the bond between them. The advantage of the UV-curing epoxy is fast curing time and no need for high temperatures. Today UV-curing epoxy was developed to bond to metal with similar performance compared to 2-part epoxies. RTV adhesive is a rubber like epoxy and does not react with most chemicals. It is found useful in some applications due to low elastic modulus, but its lapshear strength is couple times lower compared to other epoxies.

Authors discuss the properties that should be considered when choosing an epoxy. Viscosity is an important property for uncured adhesives. High viscosity makes the control of the bond easy (size, position and handling). The disadvantage of the highly viscous adhesives is that the bonds might not be as strong as for the low viscous epoxy. This is due to wetting effect – the ability of the uncured epoxy to make contact with the substrate.

Another important property is strength. There are several definitions of strength for epoxy: tensile, lapshear, peel or cleavage. The peel and cleavage strengths are much lower than tensile and lapshear. That is why it is important to design bonds with minimal stress on peel and cleavage.

If the instrument with such bonds is to be operated at wide temperature range it is important to take into an account the CTE of the glass, substrate and adhesive. Different CTE of the glass and the metal will create the displacement with the change of temperature. This will result in high stresses at the locations of the bonds. As a rule of thumb the CTE of the glass and metal should be closely matched, and then the CTE of the adhesive should have value close to the substrates.

We should also consider the typical shrinkage of the epoxy (3-5%). The UV-curing epoxy might have this value lower than 0.2%. Another unfavorable property of the adhesives is outgassing. It is very important for vacuum systems. NASA has determined that space qualified materials should have total mass loss <1%.

Authors tested 3 different epoxies represented in Table 1. Scotchweld 2216 epoxy is much known as a good 2-part epoxy and it is NASA certified. 724-14C is another 2-part adhesive but it has different structure. OP-16 is a UV-curable epoxy with low shrinkage and high lapshear strength. All these adhesives were tested on aluminum mount with three different glasses (Table 2): Pyrex, BK-7, Fused Silica. These glasses are commonly used for making optical elements. The choice of the glass to be used depends on the application and the properties of the glass.

Adhesive	2216 B/A gray	724-14C	OP-61
Supplier	3M	Ablestik	Dymax
Type	2-part epoxy	2-part urethane	1-part
Comments	High strength epoxy and low out-gassing	Flexible high strength	Multi-purpose glass to metal bonding Low shrinkage and low out-gassing
Cure	Room temp	Room temp	UV light
Viscosity	100,000 cps	High	160,000 cps
Work Life	90 minutes	30 minutes	n/a
Durometer	D 60	A 92	D 85
Shrinkage upon cure	3% (est.)	3% (est.)	0.3 %
Lapshear Strength Al-Al @ 25°C	2500 psi	1900 psi	2800 psi
Peel strength	25 piw	N/a	n/a
Glass Transition Temperature	40 ° C	N/a	70 ° C
CTE Below Tg Above Tg	 102×10^{-6}/°C 134×10^{-6}/°C	N/a	 43×10^{-6}/°C 59×10^{-6}/°C
Modulus			2,400,000 psi
TML	1.01	1.11	1.22
CVCM	0.05	0.12	0.02
Temperature Range	-55°C to +100°C	-55°C to +125°C	-45°C to +170°C

Table 1. Epoxies that were used for testing.

Material	Pyrex	BK-7	Fused Silica
Comments	Inexpensive high temperature glass	Borosilicate glass with excellent optical quality	Synthetically fused quartz for critical optical requirements
Density	2.23 g/cc^3	2.53 g/cc^3	2.2 g/cc^3
CTE	3.6×10^{-6} / °C	7.1×10^{-6} / °C	0.56×10^{-6} / °C
Young's Modulus	N/a	11,700,000 psi	10,600,000 psi
Tensile Yield Strength	3,000 psi	1,000 psi	7500 psi
Index of refraction, n_d	1.473	1.5168	1.459
Optical transmission	325 nm to 2500 nm	325nm to 2500 nm	190 nm to 4400 nm

Table 2. Optical glasses that were used in the tests.

Glass Type	Adhesive	Long term ambient stability	Angular movement from –30°C to+55°C	Comments
Aluminum Flat Plate				
Fused Silica	3M 2216 B/A	< 15 μrad	For 0°C to +55°C < 60 μrad no data @ –30°C	Large CTE mismatch caused distortion at –30°C.
Fused Silica	AbleBond 724-14C	< 10 μrad	< 200 μrad	This more flexible adhesive reduced distortion but lacked stability.
BK-7	3M 2216 B/A	< 45 μrad	< 80 μrad	Closer CTE match improved performance.
3 Raised Pads on Aluminum				
Pyrex	AbleBond 724-14C	< 150 μrad	< 85 μrad	Well defined geometry provides improvement relative to flat plate.
Pyrex	OP 61	< 100 μrad	< 20 μrad	
Counterbore Recess in Aluminum				
Pyrex	3M 2216 B/A	< 50 μrad	< 100 μrad	Similar performance. Most movement from more flexible 724-14C adhesive.
Pyrex	AbleBond 724-14C	< 50 μrad	< 200 μrad	
Pyrex	OP 61	< 70 μrad	< 80 μrad	
BK-7	3M 2216 B/A	< 30 μrad	< 50 μrad	Improvement from better CTE match for BK-7 vs. Pyrex.
BK-7	AbleBond 724-14C	< 50 μrad	< 200 μrad	
BK-7	OP 61	< 70 μrad	< 90 μrad	
Injection Side Holes in Counterbore Recess in Aluminum				
BK-7	3M 2216 B/A	< 15 μrad	< 80 μrad	Results similar to counterbore but much easier to bond and to control adhesive on edges only.
BK-7	AbleBond 724-14C	< 50 μrad	< 90 μrad	
BK-7	OP 61	< 45 μrad	< 100 μrad	
3 Pad Flexure Mount in Aluminum				
BK-7	3M 2216 B/A	< 80 μrad	< 45 μrad	All adhesives result in very stable performance during temperature exposure.
BK-7	AbleBond 724-14C	< 60 μrad	< 60 μrad	
Fused Silica	AbleBond 724-14C	< 100 μrad	< 50 μrad	
Fused Silica	OP-61	< 30 μrad	< 30 μrad	
Pyrex	OP61	< 80 μrad	< 60 μrad	

Table 3. Results of the angular stability measurements for different glasses and adhesives.

After the optical flats were bonded to aluminum plate and cured authors performed measurements on angular deviation for long term stability and temperature change. One inch diameter and 0.25 inch thick optical flats were used for each test. In each case 3 adhesive bonds were used. Authors tried to accomplish all the following common practices: definition of a plane, controlled and consistent adhesive application, minimum use of adhesive and adequate bond area for strength. The angular stability then was measured as the parallelism of the test optics surface to the reference mirror surface on the test fixture. The resolution of the measurement was better than 20 microradians. The tests were performed after bonding, after and during temperature change of the environment, and after storage time. It is important to note that this method cannot quantify the deformation of the surface.

The result of the angular stability measurement is presented in Table 3. From the result we can conclude that UV-curing epoxy can have similar performance compared to the traditional epoxy. It has similar lapshear, tensile and peel strengths, lower CTE values and much lower shrinkage during curing process. Shrinkage is an important parameter since during the curing process it will create optical element movement and high stresses.

Conclusion

This paper addresses the potential use of UV-curing epoxy for glass-metal bonding. It provides angular stability results for the long term storage and the change of temperature in the range -30 to 55 C^o. The results show similar performance of the UV-curing adhesive compared to the traditional epoxies, although the measurement values are on the order of the measurement accuracy. This paper does not provide the information on the deformation of the optical flats. This would identify if lower CTE epoxy will have better performance for the temperature tests. Authors point out that UV-curing epoxy has low shrinkage and thus will have much less stress after curing, but they do not provide any supporting results.