Local Stress Analysis at the Bond Area

OPTI 523 project preliminary design report Tianquan Su

My project is not a specific design problem but a general analysis research. I will not show a mechanical design that can be realized by others at the end. Instead, I will look into some problems that has been ignored in previous works, trying to find out some relationships that will help in opto-mechanical designs.

Introduction

Adhesives are now widely used in optics assemblies as a substitution to fasten. Bonding brings in some advantages such as convenient operation, fast, low cost, as well as provides enough mechanical properties. One problem with adhesive bonds is that substrates with different CTE(coefficient of thermal expansion) will bring in stress at the bond area while the environment temperature changes. The introduced thermal stress will exert some effects on the substrates. In the case that a mirror is bonded on the back, the stress will cause the deflection of the mirror surface in vicinity of the bond area. This is a small effect. But in high performance optics, this could be a potential problem tearing down the performance.

Another case is that the calculation of the thermal stress at the bond area. The following equations are from Vukobratovich's notes and Yoder's *Opto-Mechanical Systems Design*.

$$\tau_{\max} = \frac{(\alpha_1 - \alpha_2) \quad \Delta T \; G \tanh(\beta L)}{\beta \, h_r}$$

$$\beta = \left[\frac{G}{h_r} \left(\frac{1}{E_1 h_1} + \frac{1}{E_2 h_2} \right) \right]^{\frac{1}{2}}$$

One can see that the adhesive expansion effect is ignored in these equations. In fact, the CTE of adhesives are several times or orders larger than the most common substrates in optical sciences, say, glass and metal. There will be some differences if the adhesive expansion is taking into account.

All these introduced problems involve the thermal stress in local area of the bond that has not been studied. In this project, I will look into the local stress of the bond area hoping to provide some help to solve the above problems.

Objective

The objectives of this project are as follows:

1. Provide the radial shear stress distribution in the bond under environment temperature change. The expansion of adhesive itself will be studied. It should take into account the bulge effect at the edge of the bond, and the constraint in the normal direction of the bond. A parametric relationship (like a distribution chart) should be provided as the result.
2. Find out the relationship between the adhesive properties, bond geometry (thickness and area), and the mirror thickness with the surface deflection. Parametric results are also expected. Equations or charts should be provided. So with knowing of the properties of the adhesive and substrates, one should be able to calculate or look up the corresponding deflection on the mirror surface.

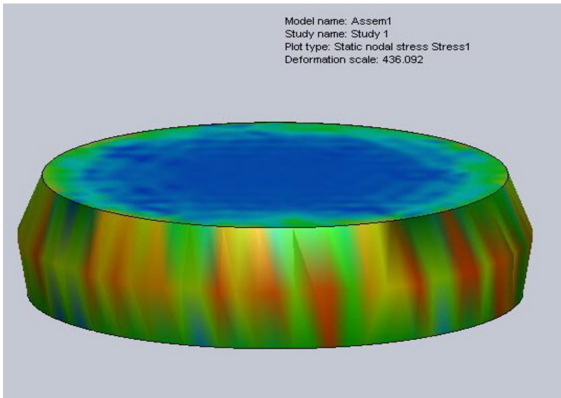
Both analysis and tests are required in this project. The test result will be used to check the analysis result.

Three adhesives will be analyzed: Milbond, GE RTV 566, 3M 2216. These are adhesives used a lot in the Large Mirror Lab in University of Arizona.

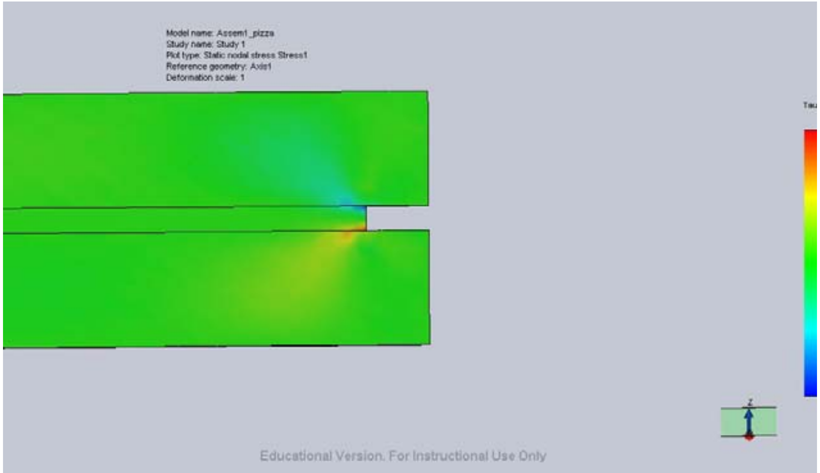
Analysis Plan

FEA (Finite Element Analysis) will be performed to analyze the local stress of the bond.

The FEA program COSMOSWorks embedded in SolidWorks will be used to do the analysis. COSMOSWorks is a powerful program for FEA. A picture is shown as follows. One can see that the bulge effect is well modeled by the program.



To show the radial stress distribution, a rotational part (like a slice of pizza) will be modeled with proper restraints.



More understanding about how COSMOS works is needed to make sure the result is wanted. Helps and tutorials in SolidWorks are helpful resources.

Equations from certain papers addressing material properties will be used to roughly check the result of the program.

Test Plan

Adhesive bonds will be put into a temperature chamber and tested by interferometer.

B-270 windows surface will be tested first by interferometer. This will be the reference data of following test. Then two pieces of glass window will be bond together, so when temperature changes the substrates jointed by the bond will expend exactly the same. In this way, one can obtain a pure effect of the adhesive joint.

Milbond and RTV 566 will be tested first. For each adhesive, two different areas and four different thicknesses will be tried.

The bond will be made in room temperature and then heated up in the temperature chamber. Samples will be tested under 40˚C and 30˚C.

The hardware preparation status are as follows:

Name	Status	Description
Glass (B-270)	Ready	2” diameter, 0.91 mm thickness
Adhesives	3M2216 ready RTV 566 to be ordered	RTV 566 and Milbond need to be ordered

	Milbond to be ordered	
Interferometer	Under adjustment	Zygo interferometer
Temper-chamber	Designed Under construction	Use a beach cooler as chamber. Window for the chamber has been made. Heater is ready.
Micrometer syringe	Ready	For small amount adhesive control