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Stress in Acrylic Bond Joints

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Abstract

Stress that arises when making thick acrylic bonds has been measured using encapsulated and surface mounted strain gages. Internal stress levels of approximately 1kpsi were recorded.

1 Introduction

The Sudbury Neutrino Observatory (SNO) will make use of a 40 foot diameter sphere, constructed entirely from acrylic, to contain 1,000 tonnes of D_2O. Since the SNO laboratory is situated at the 6,800 foot level of the Creighton mine, the vessel must be built in situ from panels which fit down the mine shaft. These panels will be joined using 0.125 to 0.25 inch thick bonds of reactive, acrylic based adhesive.

When this adhesive polimerizes it contracts by as much as 12% which results in tensile stress developing at the interface of the adhesive and the acrylic if the two panels are not free to move with respect to each other. This stress may be removed by annealing and if this is not done the bond will deteriorate with time as stress crazing is initiated. Unfortunately it will not be possible to anneal the completed sphere in the mine and it is therefore desirable to know the approximate level of stress one can expect in a bond joint.

2 Technique and Apparatus

It was proposed to measure the stress that developed as the bond cured by embedding a strain gage inside the bond joint. Measuring the resistance of the strain gage before and after curing of the bond allows the stress to be calculated. In addition, two gages were mounted on the surface of the acrylic each side of the bond to record the strain resulting from the forces transmitted into the acrylic. The position of the gages can be seen in figure 1. To prevent the two blocks moving together as the bonding material contracted, acrylic shims were placed at each end of the joint. These are shown in figure 1. The shims also fixed the bond gap to be 0.125 inches.
The strain gages used were a general purpose type [1].The gage consisted of a constantan grid completely encapsulated in polyimide. The gage length was 0.062 inches and width 0.120 inches. To facilitate positioning the gage in the joint it was first glued to a 1mm thick acrylic carrier as shown in figure 1.

It was unknown what the bonding material would do to the polyimide encapsulation of the gage so a prototype test specimen was prepared by the acrylic fabricators [2]. The resistance of the gage was recorded before and after bonding and the results indicated that stress developed in the bond, furthermore the bonding material did not appear to attack the polyimide encapsulation of the gage. To further confirm that we were indeed measuring stress in the joint, the bond was cut away from the two blocks which should in theory allow the joint material to relax; the resistance of the strain gage was seen to return close to its original value. All measurements of gage resistance were carried out at 21 ± 1°C using a Keithley 196 DMM and the Kelvin, 4-wire measurement technique. The nominal resistance of the gage

[1] Gage type CEA-06-62UW-350, Measurements Group Inc, Raleigh, North Carolina.

[2] All bonding was carried out by Reynolds Polymer Technology Inc., 311 E. Alton, Santa Ana CA 92707.

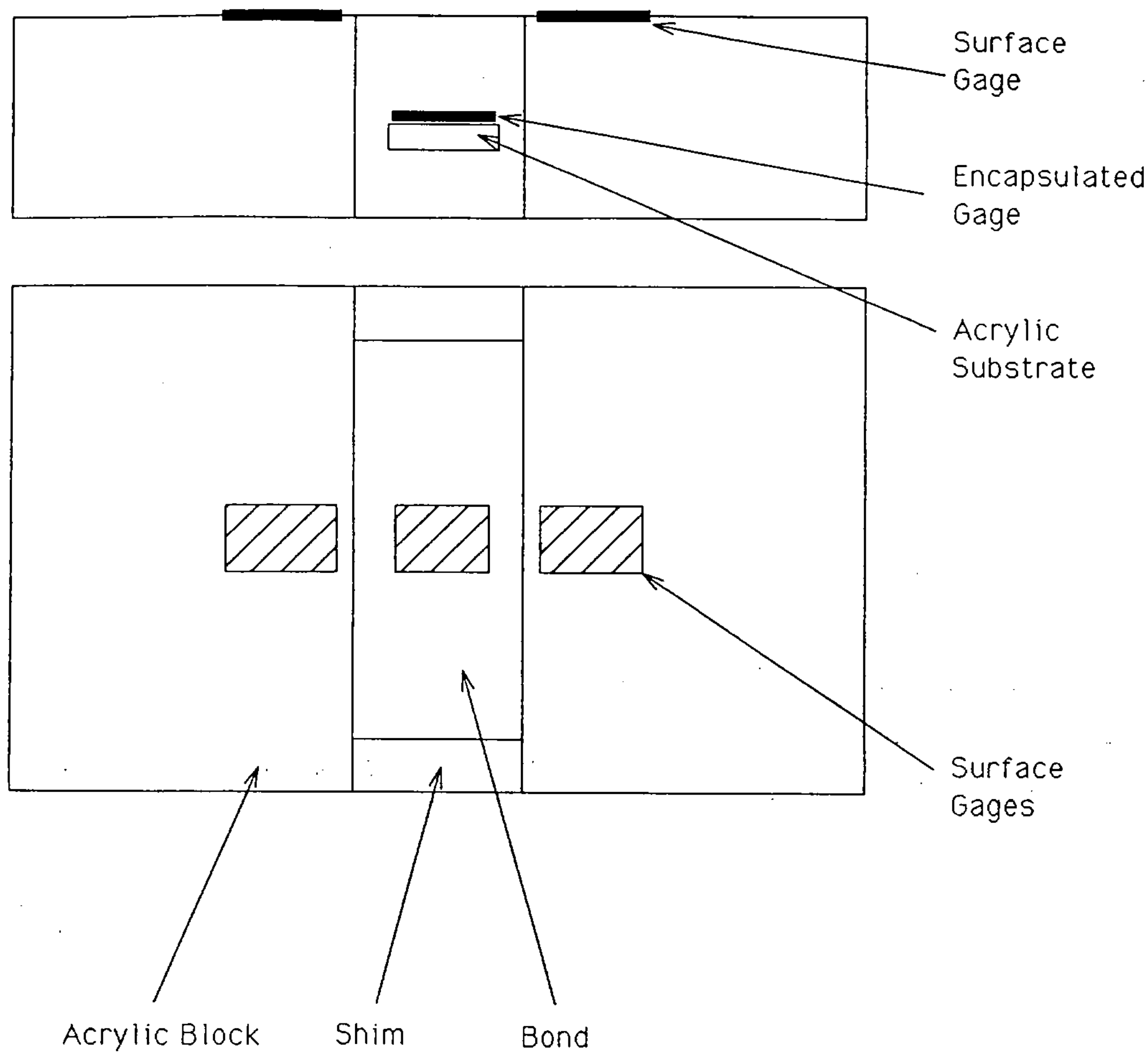

Figure 1: Schematic of a bond joint showing location of stress gages.

was 350Ω and the resolution of the meter in this mode was 100$\mu\Omega$. The results of the prototype specimen are presented below.

3 Procedure

Blocks of UVT acrylic [3] were prepared, sufficient to make three bond joints. The acrylic blocks measured X inches by Y inches by 2 inches thick. The X inch long faces were to be bonded together. Gages were mounted on the acrylic carriers and their resistance recorded. The components were shipped to the acrylic fabricator where they were bonded using a proprietary process. The bonds were not annealed. Upon returning to LANL the two external gages were mounted as shown in figure 1 and their resistance recorded along with the resistance of the encapsulated gage. The bond material was then cut away from the acrylic, care being taken not to damage the strain gages, (unsuccessful as noted by "failed" in table 2). This would relieve the strain in the material. The resistances of the gages was again recorded. The whole sequence of measurement - cutting - measurement was completed in a period of less than an hour.

4 Results

In calculating the stress it was assumed that Youngs modulus for the acrylic was 400,000psi. Table 1 shows the results for the prototype test specimen. The encapsulation stress was measured approximately 2 weeks after the bond was made. The stress is compressive indicating that the bonding material contracted around the gage. Immediately after cutting the bond free from the acrylic the resistance of the gage was again recorded and found to have almost returned to the value before encapsulation.
It should be remembered that Youngs modulus was assumed to be 400,000psi when calculating the stress. While this is a reasonable value for virgin acrylic, it is not known if the bond material has the same modulus.

[3] Supplied by Polycast Technology Corp., 70 Carlisle Place, Stamford, CT 06902.

Stress after encapsulation in bond	530psi (compressive)
Stress after cutting bond free	40psi (compressive)

Table 1: Internal stress in prototype test specimen.

SAMPLE #	GAGE #	AFTER ENCAP.	AFTER CUTTING
SAMPLE 1	A	N/A	20psi
	B	N/A	49psi
	C	1,020psi (compressive)	Failed
SAMPLE 2	A	N/A	110psi
	B	N/A	110psi
	C	450psi (compressive)	Failed
SAMPLE 3	A	N/A	160psi
	B	N/A	41psi
	C	1,180psi (compressive)	Failed

Table 2: Surface (A,B) and internal (C) stress results for 3 specimens

The results from the three test specimens are given in table 2. Unfortunately, while cutting free the bond, the internal strain gages were destroyed.

5 Discussion

As expected the internal strain gage recorded compressive stress as the bonding agent contracted around it. A mean compressive stress of 795 ± 156psi is obtained if one includes the prototype test sample results also. It is assumed that this in turn appears as a tensile stress across the acrylic-bond interface. When the external surface gages were attached, the surface of the acrylic was in tension. It is assumed that the tension is maximum in the bond and is constant until the acrylic-bond interface and then decreases according to some smooth function of distance as one moves away from the interface. When the bond is cut free, the surface of the acrylic that was in tension and to which the external gage is attached, will spring back, putting the gage into compression. The compressive strain recorded by the gage should be less than that experienced at the acrylic-bond interface (since the gage was not located exactly at the interface) and will reflect the mean stress value associated with the location of the gage. The mean distance of the center of the gage was 0.125 inches from the interface and the mean compressive stress after cutting the bond free was 63 ± 21psi. The large spread in the results may possibly be attributed to the strong dependence of stress as a function of distance from the bond interface plus the uncertainty in the mean position of the gage from the interface.

6 Recommendations

If one wishes to avoid crazing in acrylic over a ten year period, the results of long term tests [4] indicate that the tensile stress should not exceed 800psi. If we assume that the stress in the bond is constant across its width and falls approximately linearly with distance away from the bond, then based on locked in bond stresses alone it appears that we will see crazing in the bond, but that the crazing in the acrylic will be restricted to within approximately 0.1 inches either side of the bond.

This is exactly what is seen in the bond joints of acrylic diving spheres which have seen 20 years service. It would appear that from the optical point of view, the problem of stress crazing is not a serious one in the SNO sphere. Mechanically, it is clear that placing bonded test specimens under stress in the SNO environment and testing them periodically will be a wise move. Should accelerated deterioration be observed, corrective action can be taken.

[4] J.D. Stachiw, J. L. Stachiw, Crazing and Degradation of Flexure Strength in Acrylic Plates as a function of Time, Naval Ocean Systems Center, San Diego, CA 92152-5000, Technical Report 1303, June 1989.