Recent results of hydroxide catalysis bonding for cryogenic suspensions

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Introduction

Interferometric gravitational wave (GW) detectors have used carefully-suspended fused silica test masses to minimise thermal noise[1]. Reducing the loss will reduce the thermal noise - some planned detectors aim to do this through cryogenic cooling. At ~40 K, silica has a well-defined loss-peak[2], hence crystalline materials such as silicon and sapphire are of interest for the aLIGO upgrade and for future detectors such as the Einstein Telescope and KAGRA. This poster reports progress in on-going experiments involving hydroxide catalysis bonding with sapphire and silicon to investigate suitability for use in the assembly of quasi-monolithic suspensions. The effect on strength of longer curing times for sapphire bonds is considered, as is the effect of thermal cycling silicon bonds.

Bonding

The hydroxide catalysis bonding technique consists of three stages; hydration and etching, polymerisation and dehydration. For bonds to be successful and strong, the surfaces to be bonded must be flat (<λ/10), and clean (see Figure 1 for examples of bonded sapphire and oxidised silicon samples). All bonds here were made with sodium silicate solution and were cured at room temperature.

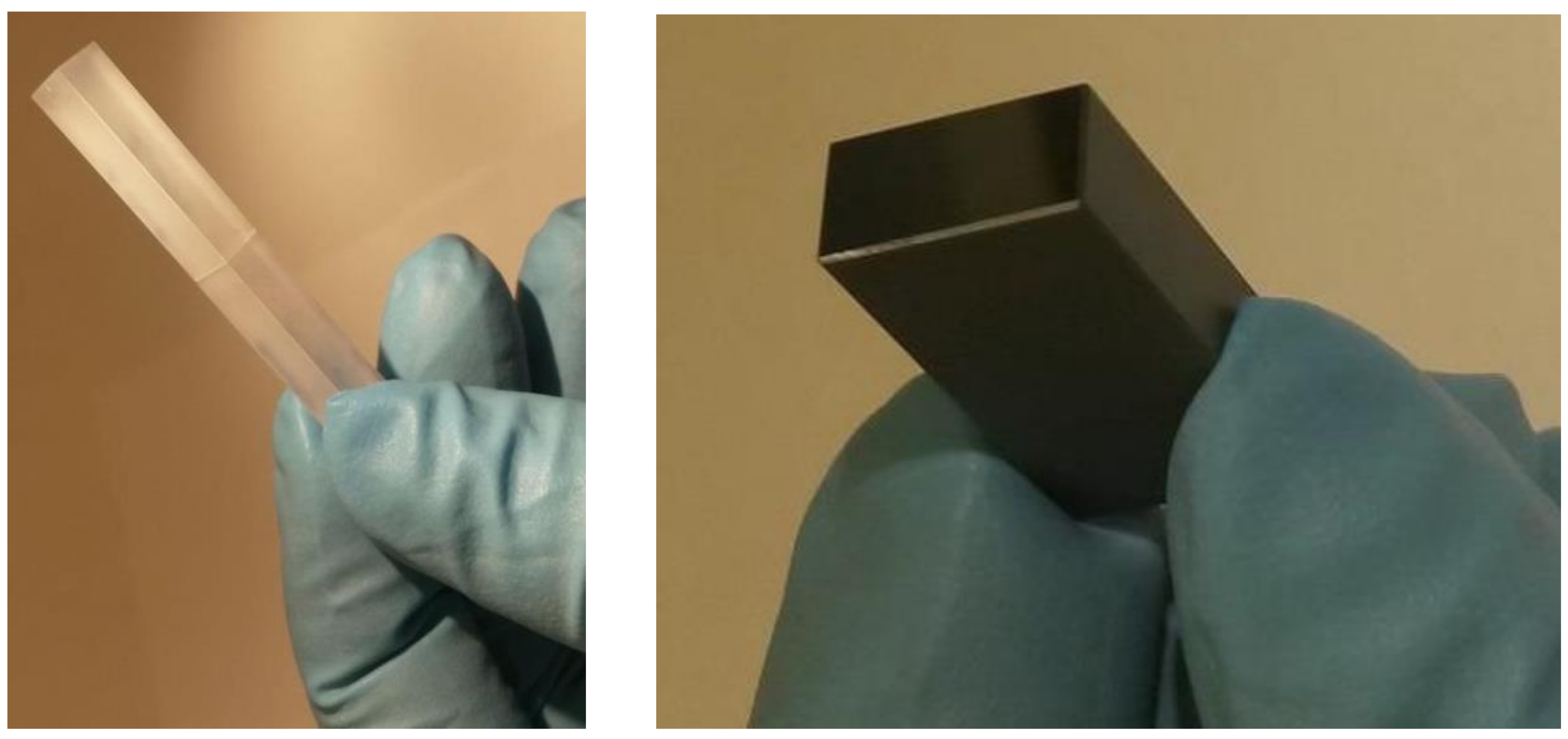

Figure 1. Photographs showing and example of bonded sapphire samples (left) and an example oxidised silicon block before bonding (right).

Thermal cycling of silicon bonds

Any quasi-monolithic suspension built with crystalline materials is likely to be thermally cycled between room temperature and operation temperature.

Four sets of 10 bonds were made with silicon samples, including a control set and three further sets which were to be thermally cycled 3, 10 and 20 times respectively. After curing for four weeks at room temperature, samples were thermally cycled between room temperature and ~4 K. Each cycle took ~2 hours, a time chosen with the aim of ensuring samples had time to come to equilibrium. The tensile strengths of the bonds were then measured at room temperature. See figure 3 for strength results.

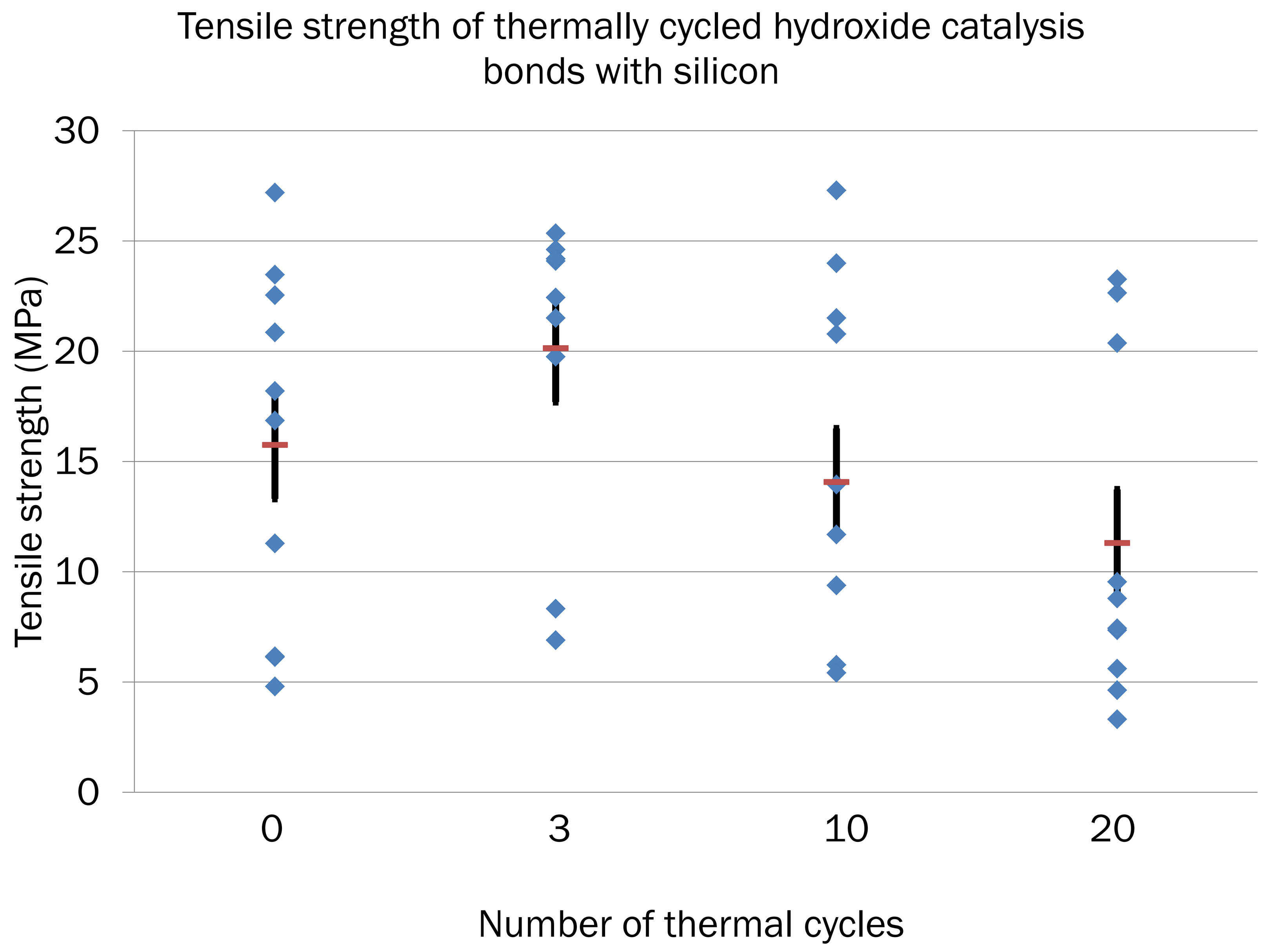

Figure 3. Tensile strengths of hydroxide catalysis bonds formed with silicon after thermal cycling. The strength of bonds does not appear to be negatively affected by thermal cycling although there is some spread in the results. One possible cause for this is that, since bond quality cannot be visually inspected in silicon bonds, some of the weaker bonds would have been of inferior quality and might normally have been rejected.

Strength testing

The tensile strength of the bonds was measured here using a four-point bending test as shown in figure 2. In this test the force is applied through a load arm and is steadily increased. The force required to break the bond is used to calculate the tensile strength as according to,

$$\sigma = \frac{3(L-l)F}{2bd^2}$$

Where σ is the tensile stress, L is the distance between the contacts beneath the sample, l is the distance between the contracts above the sample, F is the maximum force applied, b is the sample thickness and d is the sample width.

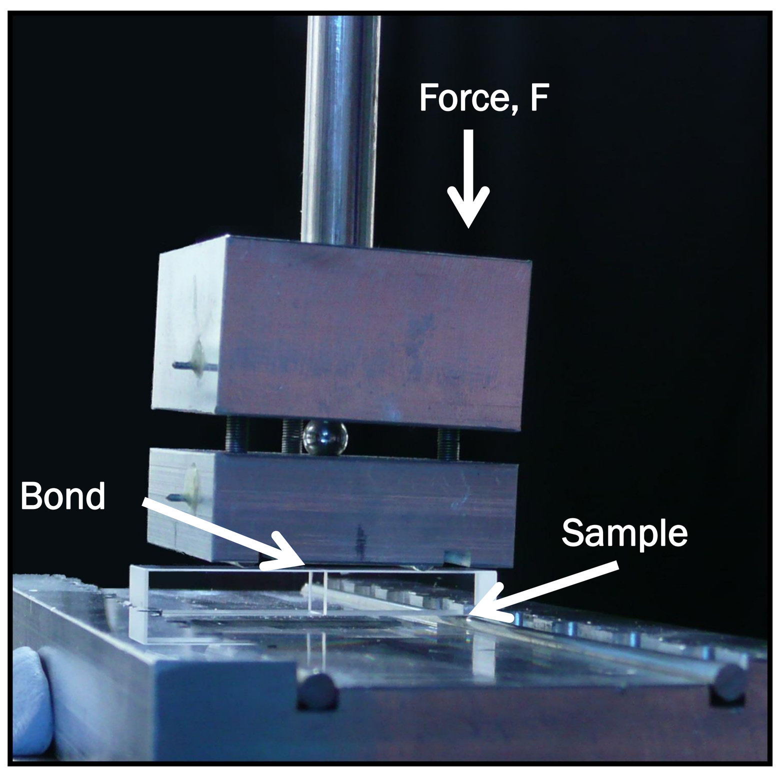

Figure 2. Photograph of a pair of bonded sapphire samples in a 4-point bending test. This test is used to measure the tensile strength of a hydroxide catalysis bond.

Curing time of sapphire bonds

In the past hydroxide catalysis bonds formed with fused silica have been found to reach their full strength after four weeks of curing at room temperature. Given the chemical differences between fused silica and sapphire it is important to investigate whether the curing time is any longer for sapphire.

Four sets of 10 bonds with formed. Three were cured for 4, 8 and 12 weeks. A fourth set was cured for 1 weeks at room temperature and 1 at 40 °C. The tensile strengths of the bonds were then measured. See figure 4 for the strength results.

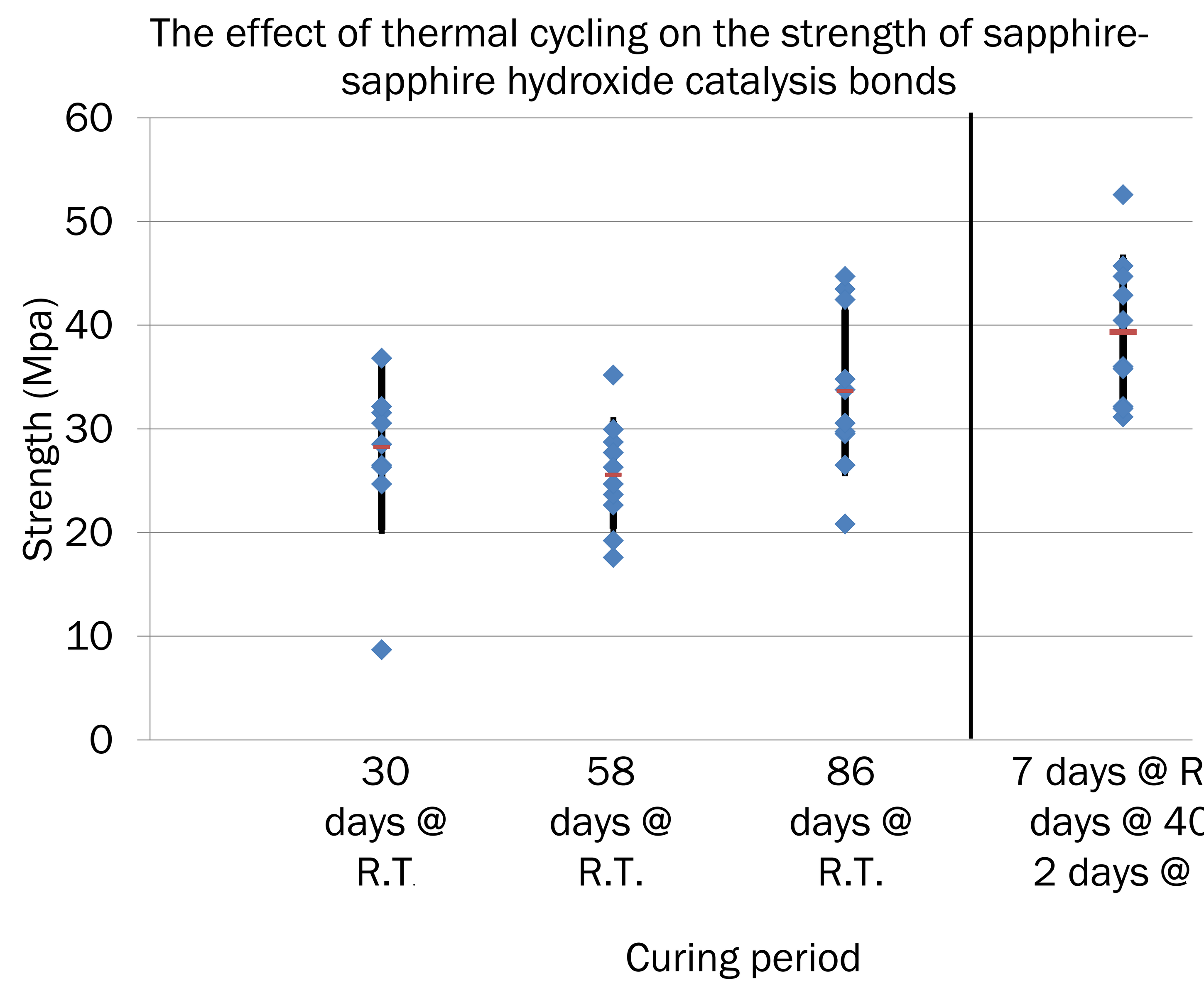

Figure 4. Tensile strengths of hydroxide catalysis bonds formed with sapphire and cured for 4, 8 and 12 weeks at room temperature and for those cured for 1 weeks at room temperature and then for 1 weeks at 40 °C. Curing for additional weeks does not appear to be necessary for sapphire bonds to reach their full strength.

Conclusions

Sapphire bonds appear not to benefit from curing for additional time beyond the standard four weeks, however, heat treating bonds may have some beneficial effects in terms of strength.

Silicon bond strength is not adversely affected by thermal cycling, at least up to 20 cycles between ~4 K and room temperature. However, it is clear that there is quite a wide spread of results and these results appear to be grouped. The possible causes for this are under investigation

[1] S Rowan et al 2005 Phys Letters A http://dx.doi.org/10.1016/j.physleta.2005.06.055

[2] L Ju et al J. Opt. A. Pure Appl. Opt. 2009 10.1088/1464-4258/11/12/125205

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