

# Improved Bond Strength Characterization of Chemically Activated Direct Bonding (CADB<sup>®</sup>) Epoxy-Free Bonded Solid State Laser Materials

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## ABSTRACT

Chemically Activated Direct Bonding (CADB<sup>®</sup>) has become widely utilized as an epoxy-free assembly process for solid state laser crystals in high fluence and other aggressive environments. While data has been presented as to both optical and mechanical properties of these bond interfaces, previous research has hinted that sample preparation plays a large part in the final results. Surface finish of samples and any surface defects or sub-surface damage present can lead to artificially low strength values and other inconclusive results. In the current study, we prepared samples with polished surfaces to improve the accuracy of the bond strength measurements. Here we present strength data for bonded and bulk samples of common laser materials such as YAG, phosphate glass, and fused silica.

**Keywords:** CADB, epoxy-free, YAG, phosphate glass, fused silica, bond strength, laser materials

## 1. INTRODUCTION

We present a method for bonding highly doped phosphate glasses, YAG, and other laser gain media to handling substrates or cladding materials. The Chemically Activated Direct Bonding (CADB) technology results in epoxy-free optical paths that are 100% optically transparent with negligible scattering and absorptive losses at the interfaces. It offers bond performance equivalent to that of the bulk materials being bonded, and has been proven to be exceptionally durable, reliable and resistant to laser fluence, temperature, and humidity<sup>1</sup>. The focus of this work is to more accurately characterize mechanical performance data at the bond interface.

### 1.1 Previous Work

The CADB process has been shown to give near-bulk strength in laser gain materials such as YAG and phosphate glass<sup>2</sup>. In this previous work, 3mm x 3mm x 6mm samples both with and without a bond interface present at the center were broken on a small load cell set-up. A summary of this data is shown in Table 1.

Table 1. CADB bonded and bulk material strength for Ceramic YAG and Qx/Er Phosphate glass<sup>2</sup>.

	Ceramic YAG	Qx/Er Phosphate Glass
<b>Bulk Material</b>	15.1 kg	2.3 kg
<b>CADB Bonded</b>	12.6 kg	1.9 kg
<b>% of Bulk Strength</b>	83%	83%

It should be noted that these samples were prepared by first bonding larger pieces of material and then dicing them into 3mm x 3mm square samples. The “as-diced” surface finish was left on all four sides. During the experiment in Ref. 2, we found that the CADB bonded samples broke in a very consistent manner. We hypothesized that the rough-ground finish on these surfaces left over from dicing would typically lead to a defect site at the edge of the bond interface in the form of a minor chip-out, a micro-fracture extending inward from the surface, or other surface damage. The defect would result in a weak spot for the fracture to propagate from, and thus lower the strength value of these samples. Such behavior has been exhaustively studied in other applications such as fused silica optical fibers for telecommunications and YAG laser slabs<sup>3,4</sup>. In order to validate our hypothesis for the optical materials in question, we decided to perform strength tests on a new set of samples prepared with polished surfaces.

## 2. METHODOLOGY

### 2.1 Sample Preparation

Bulk samples were prepared by taking raw material samples of Qx/Er Phosphate Glass, Ceramic YAG, and Fused Silica, polishing them to a thickness of 7mm and dicing them into squares that were slightly oversized from 3mm x 3mm. Samples were then polished on all four sides to achieve a laser quality finish. The sharp corners had a slight bevel applied to break any sharp edges. To ensure that all surface damage was eliminated during the polishing, we removed at least 0.5mm of material for each of the 4 outer surfaces. Surface roughness for all three materials was identical, in the 5-9 Angstroms range.

CADB<sup>®</sup> samples were prepared in much the same way. For each material type, we used additional material from the same lot as the bulk samples. We polished two separate wafers to a thickness of 3.5mm. These two wafers were bonded together using the CADB process. The resultant wafer assembly was then diced into dimensions slightly oversized from 3mm x 3mm. Samples were then polished on all four sides to a laser quality finish and the corners had a slight bevel applied to break any sharp edges. Surface roughness for all three materials was identical, in the 5-9 Angstroms range.

Samples were therefore identical in every manner with the exception of the CADB bond line. A surface scan showing representative surface roughness of the polished sides for each sample set is shown in Figure 1.

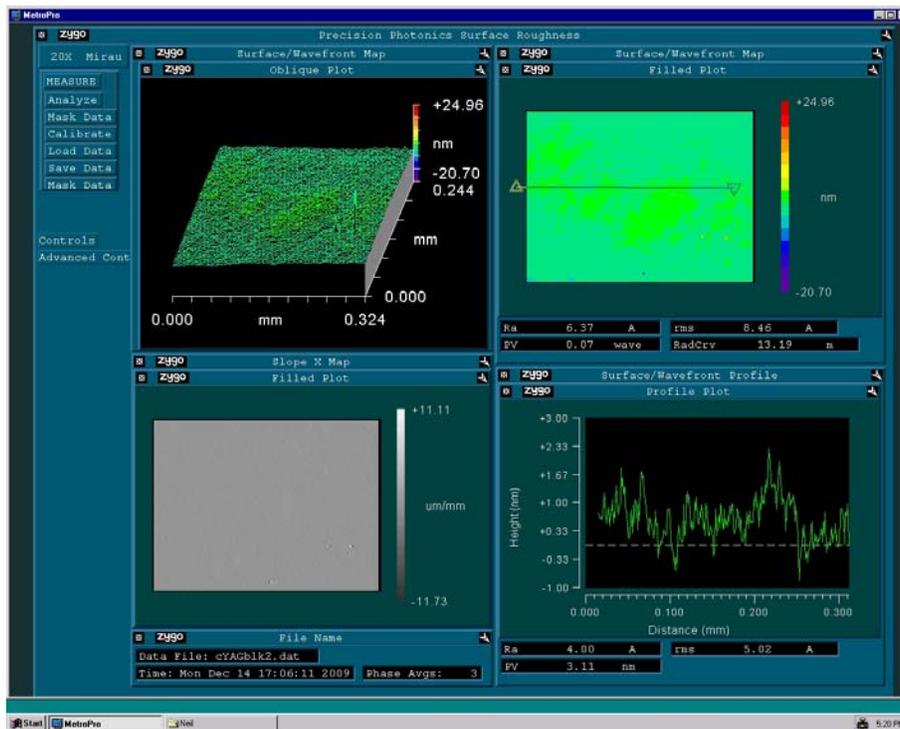


Figure 1. Surface scan of polished Ceramic YAG samples showing a surface roughness of approximately 5-9 Angstroms rms.

### 2.2 Test Fixture

Samples were then constrained in a test fixture under equal load and a force was applied to them at the same height in every sample. This force was applied until fracture was observed and the peak force was measured via an Imada DPS-110 load cell. Each sample set consisted of 10-20 identical pieces. Testing of all sample sets was performed at the same time, and by the same operator to help ensure consistency of results. A picture of this test fixture is shown in Figure 2, and a schematic with exact dimensions is shown in Figure 3.



Figure 2. Test fixture set-up for sample fracture strength measurements (phosphate glass sample is shown).

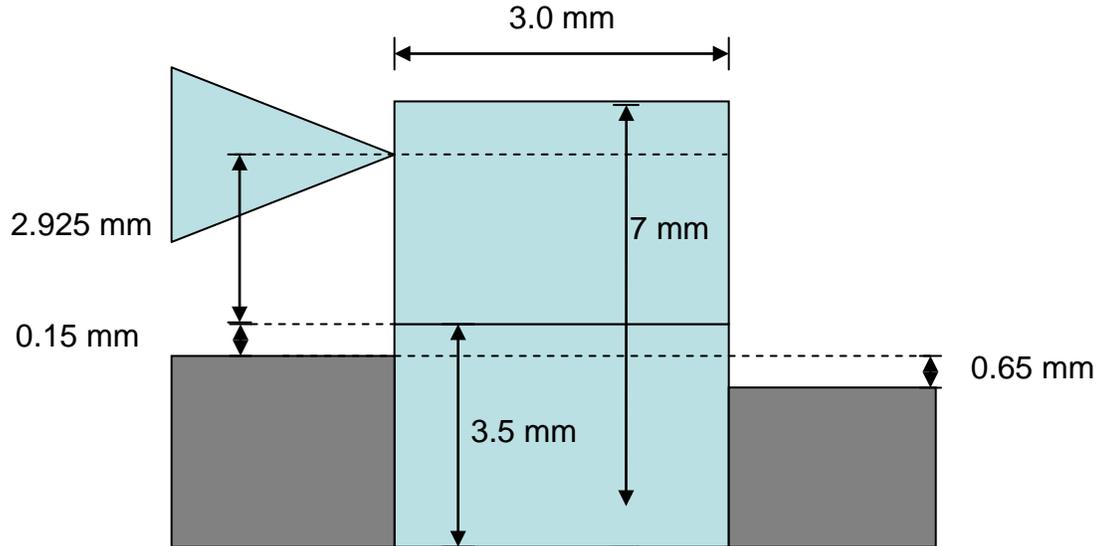


Figure 3. Schematic with exact dimensions for sample fracture strength measurements.

### 3. RESULTS

#### 3.1 Strength Results

A summary of the average strength results for each sample set is shown in Table 2. Histograms with complete strength results for each sample set is shown in Figures 4-6 below.

Table 2. CADB<sup>®</sup> bonded and bulk material strength for Ceramic YAG, Qx/Er Phosphate glass, and Fused Silica samples.

	Qx/Er Phosphate Glass	Ceramic YAG	Fused Silica
<b>Bulk Samples</b>	10.5 kg	29.9 kg	8.5 kg
<b>CADB<sup>®</sup> Bonded Samples</b>	11.3 kg	30.7 kg	9.6 kg
<b>Ratio (% of Bulk Strength)</b>	106%	106%	113%

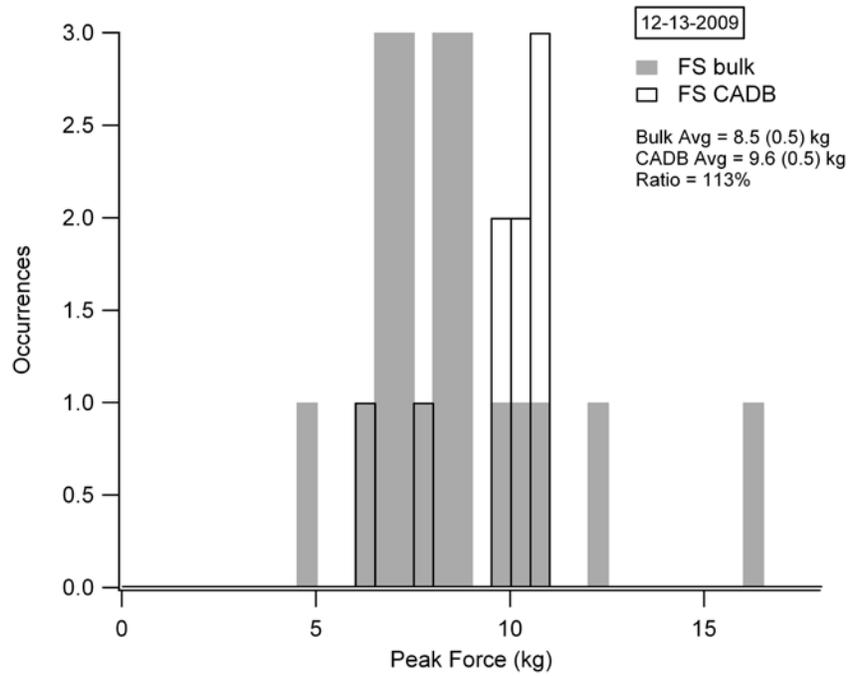


Figure 4. Fracture strength results histogram for bulk and bonded fused silica. Mean force values are given along with the computed standard deviation of the mean. The ratio is equal to the CADB<sup>®</sup> mean force divided by the bulk mean force.

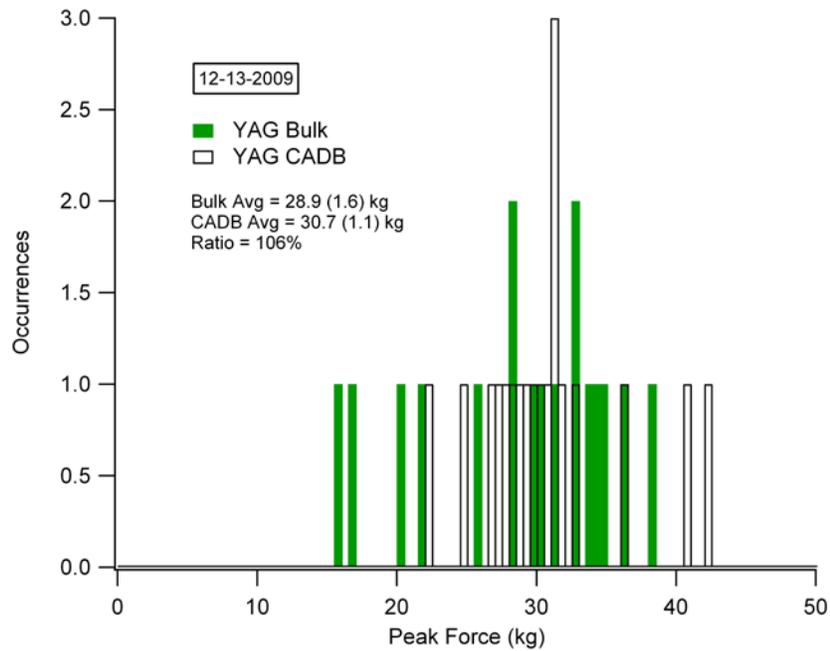


Figure 5. Fracture strength results histogram for bulk and bonded YAG. Mean force values are given along with the computed standard deviation of the mean. The ratio is equal to the CADB<sup>®</sup> mean force divided by the bulk mean force.

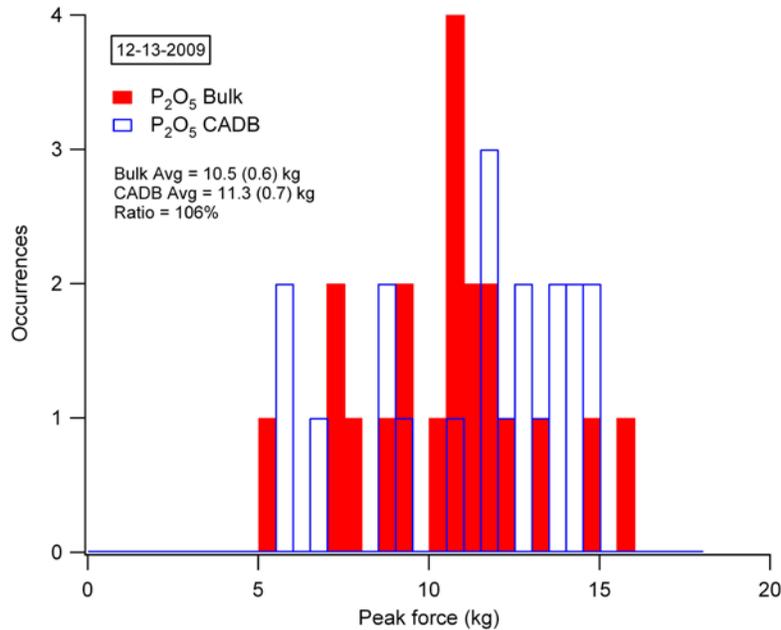


Figure 6. Fracture strength results histogram for bulk and bonded phosphate glass. Mean force values are given along with the computed standard deviation of the mean. The ratio is equal to the CADB<sup>®</sup> mean force divided by the bulk mean force.

#### 4. CONCLUSIONS

For each material type, we observed that the CADB<sup>®</sup> bonded samples tested to a slightly higher average force than the bulk samples. However, the authors would point out that this difference is within the noise of the measurement. While there are some reasons the CADB process may strengthen the samples, it is sufficient to say that the CADB bonded samples achieved similar strength values to those of the bulk. This is validated by a visual inspection of the fracture surfaces where the CADB samples and the bulk samples appear to be identical in fracture type and propagation (in nearly all cases, the CADB samples behaved like a bulk sample and did not break at the bond interface—see Figure 7).

Clearly, our results demonstrate that the quality of the finish on the surfaces adjacent to the bonded interface plays a huge role in the observed CADB bond strength, which validates our original hypothesis. For phosphate glass and ceramic YAG, we observed an increase of the ratio of CADB bonded sample strength to bulk sample strength from 83% to ~100% (compare Tables 1 and 2). This indicates that the mechanism for bond failure in our previous work<sup>2</sup> was fracture propagation from a defect side near the bond line. The fact that the strength ratio was 83% in our previous study indicates that the bonded interface is more susceptible to crack propagation, i.e., peeling apart along the bond line, than the bulk material. However, this enhanced susceptibility to failure can be completely eliminated by polishing adjacent surfaces to remove subsurface damage and micro-fractures.

Another conclusion from the current work is that the measured bulk material strength increases when the surfaces under test are polished. Comparing Table 1 and Table 2, we see that the bulk strength of the phosphate glass increased by a factor of 4.6 after polishing, while the measured ceramic YAG bulk strength increased by a factor of 2.0. These results can be explained in terms of a well known relationship from the literature of brittle materials. Previous studies of brittle materials have demonstrated that fracture stress is inversely proportional to the square root of the length of a surface crack.<sup>5</sup> As the surface fracture grows in length, the stress required to break the sample decreases. We estimate that the size of surface fractures/damage on an “as diced surface” is 50-100 microns, whereas surface fracture/damage depth is reduced to a negligible level (<1 nm) after polishing.

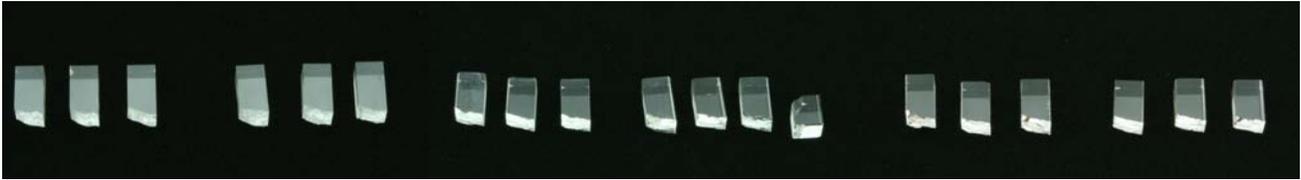


Figure 7. Examples of broken samples for all sample sets. In all cases, fracture initiated at the location of the back-side clamp corner. Propagation of the fracture usually proceeded at a slight downward angle relative to horizontal.

#### 4.1 Future Work

The CADB bonding process for three separate material sets has been more fully vetted in terms of optical performance and mechanical integrity. We believe future work should focus on specific form factors for bonded assemblies to optimize performance in various solid-state laser configurations. The authors plan to study optimal designs of CADB assemblies with regard to CTE matching, heat loading, and compatibility with real-world mounting schemes.

#### REFERENCES

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