01 Jan 2004

High Strength Epoxy as an Alternative to Welding

Eric Pieper

High Strength Epoxy as an Alternative to Welding

Eric Pieper
University of Missouri-Rolla

Abstract

This research was performed to explore the possibility of using epoxy joint connections in place of welded connections in a tube frame structural design. Welded connections work very well when the frame is made of steel, aluminum or titanium. Carbon fiber tubes are available and have a higher strength-to-ratio than the metal tubes, but the connections cannot be welded. The long term goal of this research is to be able to use carbon fiber tubing to construct the solar car chassis.

A junction made using high strength epoxy to bond an insert into the adjoining tubes can be almost as strong as a tube that has not been cut. Using a 6061-T6 aluminum tube, an insert of the same material, and Araldite 2015 two-part epoxy the junction was almost as strong as a welded connection in two different types of tests. In a 3-point bending test a sample with the glued joint yielded at bending stresses of 10 to 20 ksi. In a torsion test the glue yielded at shear stresses of 4.5 to 10 ksi. A welded connection will typically yield at 16 ksi in bending and 8 ksi in shear. Since the results are so close to the strength of welded connections, this method may be examined as an alternative to welding in some instances.

Introduction

At present the best way of joining metal tubes into a space frame structure is through welding. This method works fine when using similar metals and metals that have properties suitable to welding. If neither of these are these are the case it becomes very difficult to join the materials. Many times a specialized welding machine must be used to join the metals. Regardless of how many parts are to be manufactured, the welding machine has to be used for each.

When looking for a lightweight material with high strength properties it is very possible to find several different materials that do not have the ability to be welded. It may also be that a combination of materials needs to be used throughout the structure to achieve the greatest strength while maintaining the lightest weight. For these instances an acceptable and affordable substitute is not always available.

Epoxies have been used in the aerospace industry for several decades. Despite this, not much testing has been done for using glued joints as a replacement to the welded joints. Epoxy allows the user to be more flexible with materials used. Many epoxies will bond to a variety of materials. This makes it much less expensive to join materials that would have previously required large setup costs. For small production runs the parts can be glued by hand however, if the number of parts to be produced is large then an automated machine can be purchased to apply the epoxy.

Experimental Setup

For the experiment two different tests were conducted to determine the strengths of the samples. The first test was a three-point bending test. This was used to determine the stress at which the glue bond would break while in bending. The second test was a torsion test. This was used to determine the shear stress the bonded portion of the tube could withstand.

Samples made of 6061-T6 aluminum were used since it is often utilized in lightweight structures and the properties of welded samples were assumed to be that of the original tube. The materials used for the tests were prepared in the following manner. A tube with outer diameter of 1.125 inches and wall thickness of 0.125 inches was cut into 4 inch segments. A tube with outer diameter of 0.875 inches and wall thickness of 0.125 inches was machined slightly to fit inside the larger tube and then cut into 1.5 inch segments. Each sample consisted of two of the 4 inch segments joined with one of the 1.5 inch segments.

To prepare the samples for bonding, the insides of the 4 inch segments and the outsides of the 1.5 inch segments were etched using 100 grit sandpaper. This rough surface was then cleansed using acetone. With the surface clean Araldite 2015 two part epoxy was applied to the outer surface of the small tube and the inner surface of the large tube as specified by the manufacturer. The process is illustrated in figure 1.

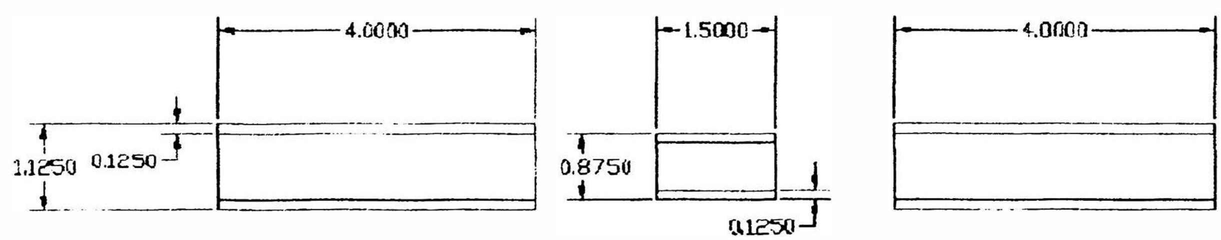

Figure 1 – Aluminum pieces for each sample

The three-point bending test tested a sample over a span of 7.0866 inches with the force applied at the junction of the sample as illustrated in figure 2. This test was done on three different samples. The test continued until the piece had failed. The data was recorded by computer.

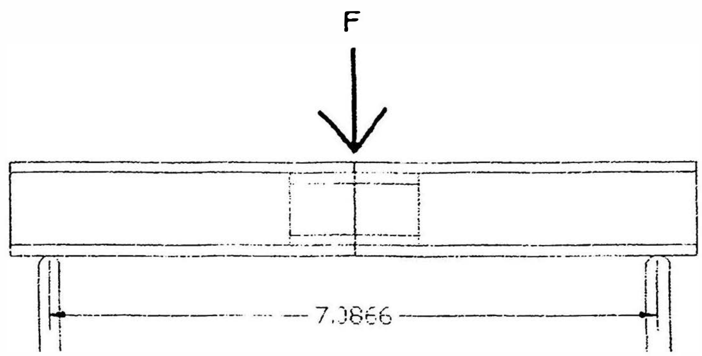

Figure 2 – Three-point bending test setup

The torsion test was completed by gripping the ends of the tubes and twisting one end as illustrated in figure 3. This test was also performed on three samples. The data was monitored as the test proceeded and the high value recorded by hand. The test was stopped when the value was no longer increasing.

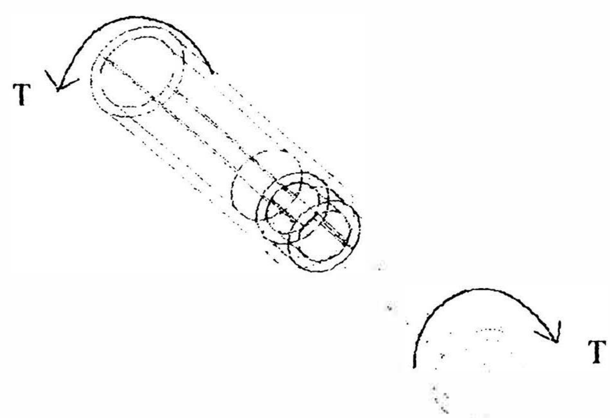

Figure 3 – Torsion test setup

Results

The data was all compared to the properties of 6061-T6 aluminum tubing with an outer diameter of 1.125 inches and a wall thickness of 0.125 inches. This gives a good comparison of the strength of the joint.

Bending Stress

The maximum stress achieved by each sample in the three-point bending test was calculated using the following equations.

$I = \frac{\pi}{64}(OD^4 - ID^4) = 0.049854 in^4$, where I is the moment of inertia, OD is the outer diameter of the tube, and ID is the inner diameter of the tube.

$M = \frac{PL}{4}$, where M is the moment, P is the load, and L is the span distance.

$\sigma = \frac{M(\frac{OD}{2})}{I}$, where σ is the bending stress. Using the numbers associated with the samples with these equations they were simplified to be $\sigma = 19.99P$.

The force used in the calculations was the point at which the force first started to drop, as illustrated in figure 4. This was assumed to be the point at which the glue yielded. After this point the insert provide even more strength by being wedged into the two sections of tube. Results of the tests are shown in table 1.

Sample #	Force	Stress(psi)
1	1048.6	20961.51
2	540.4102	10802.8
3	808.8599	16169.11

Table 1 – Bending stresses

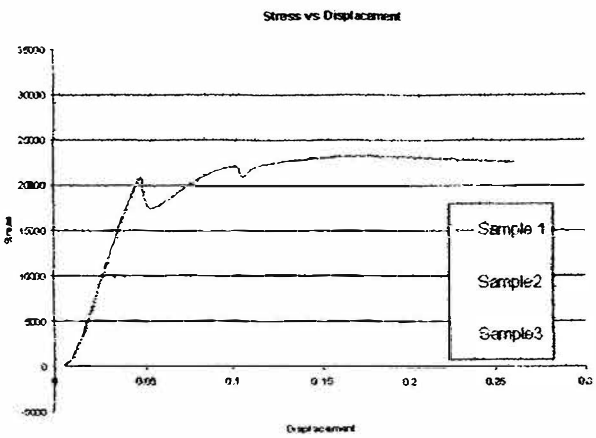

Figure 4 – Bending stress vs. displacement

Shear Stress

The shear stress of the bonded area was determined using the following formulas.

$$Area = \pi(0.875)(0.75) = 2.06167 in^2$$

$$Force = \frac{T}{radius} = (2.2857)T$$, where T is the torque

$$Stress = \frac{Force}{Area} = (1.1087)T$$

The stress in each of the samples is shown in table 2 below.

Sample #	Torque	Stress(psi)
4	1800	10154.58
5	800	4513.144
6	1440	8123.66

Table 2 – Shear stresses

Conclusions

As can be seen from the data above, the bonded tubes did not perform as well as the tube would have if it were in its original state. One sample did come close in the bending and one in the torsion test. Overall, the adhesive performed fairly well. While the test results are not quite as good as a regular tube, the adhesive did come close on several of the tests.

It was originally thought that the tube/insert junctions were the same in all instances, some of the tolerances between the two were a little larger. This may have caused more stress to be placed on the adhesive instead of the insert. The difference in the test results is most likely due to inconsistent application of the adhesive. For further testing it would be good to try and standardize the application of the adhesive and the tolerances of the insert for more uniform results.

With a more reliable setup for the samples it should be possible to consistently see results closer to the theoretical limits of the plain tube. Knowing this, it will be possible to design structures that are glued instead of welded. Since some materials cannot be welded, this method of construction may be an acceptable substitute.

Acknowledgments

I would like to thank Dr. Douglas Carroll for his guidance for this report. His experience with the material analysis and testing were invaluable.