

# USEFUL DESIGN CRITERIA FOR ACRYLIC FOAM TAPES IN DEMANDING INDUSTRIAL APPLICATIONS

Tony Kremer  
Technical Service Specialist  
3M Industrial Adhesives and Tapes Division

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## **Abstract**

Acrylic foam tapes have been demonstrated to be very capable bonding products over the past 25 years, providing an often ideal combination of performance, durability, and ease of use. They have been successfully used in a wide variety of demanding industrial applications in areas such as commercial building construction. Although these tapes have proven themselves in actual use, the viscoelastic nature of pressure-sensitive adhesives has provided a challenge for the design engineer because suitable performance values for evaluating adhesively-bonded joints have not been widely available.

A series of tests were recently performed demonstrating that acrylic foam tapes are capable of providing performance on par with other bonding materials used in the construction industry. The results from these tests have also been used to generate simple, useful, and conservative values for tape performance that can be used in design calculations. These design criteria provide sufficient performance for many construction applications, while incorporating safety factors typical of the industry.

## **Introduction**

Previous studies of pressure-sensitive adhesives and their viscoelastic properties have looked at factors such as creep, stress relaxation, fracture, and debonding mechanisms. While these experiments have helped the adhesive expert to better understand their acrylic foam tapes and to develop new products, they do not provide the performance data that mechanical engineers need to design tapes into their industrial applications. These industrial uses, such as bonding frame and stiffeners to architectural panels in building construction, require the tape manufacturer to provide design guidelines on allowable tensile and shear strength for their products under both dynamic and static loads. A methodology for obtaining such guidelines is provided here. Although the examples used herein are in the construction industry, the thought process and performance values are the same for adhesively-bonded panels in other market segments such as specialty trailers or highway signs.

Figure 1 shows a typical design for an architectural metal panel installed as part of the external cladding system on a commercial building. The panel includes an extruded L-shaped aluminum perimeter frame and three U-channel aluminum stiffeners attached to the back of either aluminum sheet or aluminum composite material (ACM). The frame and stiffeners can be attached with either stud bolts or structural silicone adhesives, but using acrylic foam tapes provides an alternative bonding method that can provide the performance needed for the application, yet with some significant benefits. Potential advantages

include faster assembly, lower total cost, immediate handling strength, improved aesthetics, low mess, consistent bond line thickness, reduced chance of read-through, and greater design flexibility.

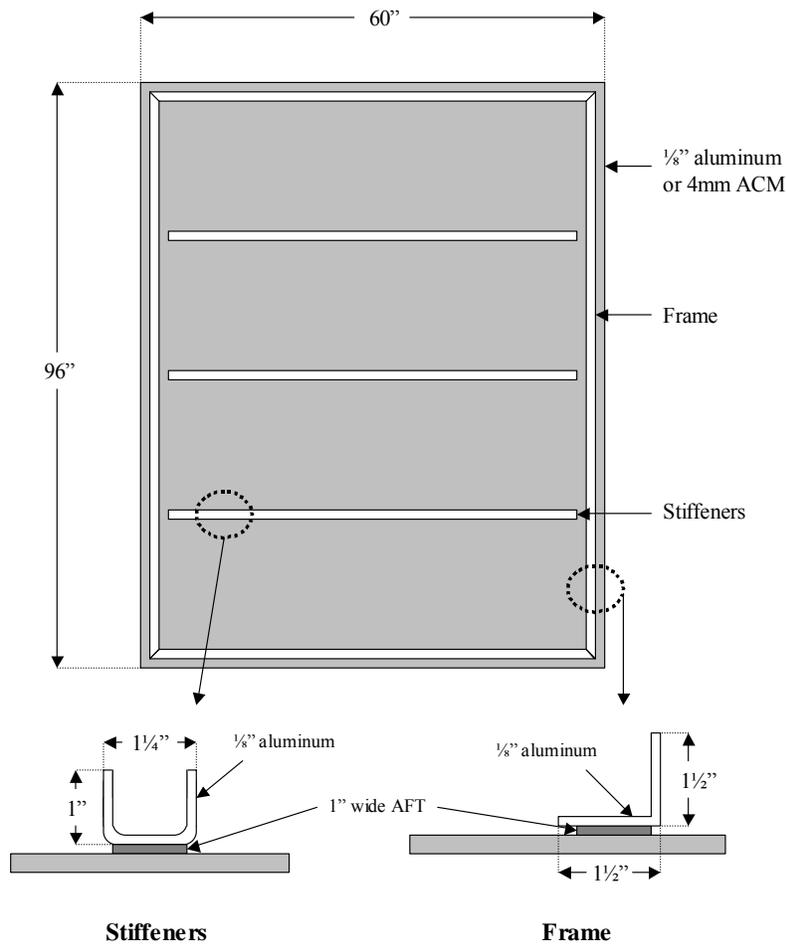


Figure 1. Architectural Metal Panel

In addition to their performance, the long-term durability of acrylic foam tapes is also critical for these applications. The ability of acrylic adhesives to withstand cold and hot temperatures, UV light exposure, humidity, and other environmental conditions has been previously documented through both real-life and accelerated aging studies and, therefore, will not be covered here.

### Constant Load Test

The generation of allowable or design stress values for an acrylic foam tape (AFT) requires knowledge of the application and, specifically, the forces exerted on the bond and the time frame over which they could be expected to act. For a vertically-mounted architectural panel attached to the outside of a commercial building, the most important forces to consider are static shear loads (due to the dead weight of the face material being supported by the acrylic foam tape along the perimeter frame) and dynamic tensile loads (from a hurricane or other high wind event). These forces are not adequately duplicated in the common overlap shear or normal tensile tests, and the peak force values recorded from these dynamic tests are not indicative of actual performance under real-life stress conditions. The peak forces

from these tests are also typically much higher than the tensile or shear strength value that should be used in a design calculation.

Regardless of whether the force acts over a short time period and thus appears "dynamic", or over a long time period and thus appears "static", the force can be studied by applying a constant load to the adhesive tape bond and measuring the time to failure. The constant load was applied instantly by either hanging a dead weight or using a tensile machine with a fast separation speed. The test was performed on three acrylic foam tapes, all suitable for use in industrial applications, with the following attributes:

- AFT #1: firm high-strength foam; adhesive bonds to high energy surfaces (0.080" thick)
- AFT #2: conformable high-strength foam; adhesive bonds to medium energy surfaces (0.062" thick)
- AFT #3: conformable medium-strength foam; adhesive bonds to lower energy surfaces (0.062" thick)

The test was performed in both tensile and shear orientation for all three acrylic foam tapes. The bonding surface for all tests was lightly abraded aluminum, cleaned with a tissue wipe using a 50:50 mixture of isopropyl alcohol and water. The tape was allowed to dwell for 72 hours at room temperature and 50% relative humidity before testing. The applied stress ranged from 5 psi to 70 psi, with the times to bond failure spread out over nearly 6 decades of time from a few seconds to several months. The following two graphs, Figures 2 and 3, illustrate typical test results.

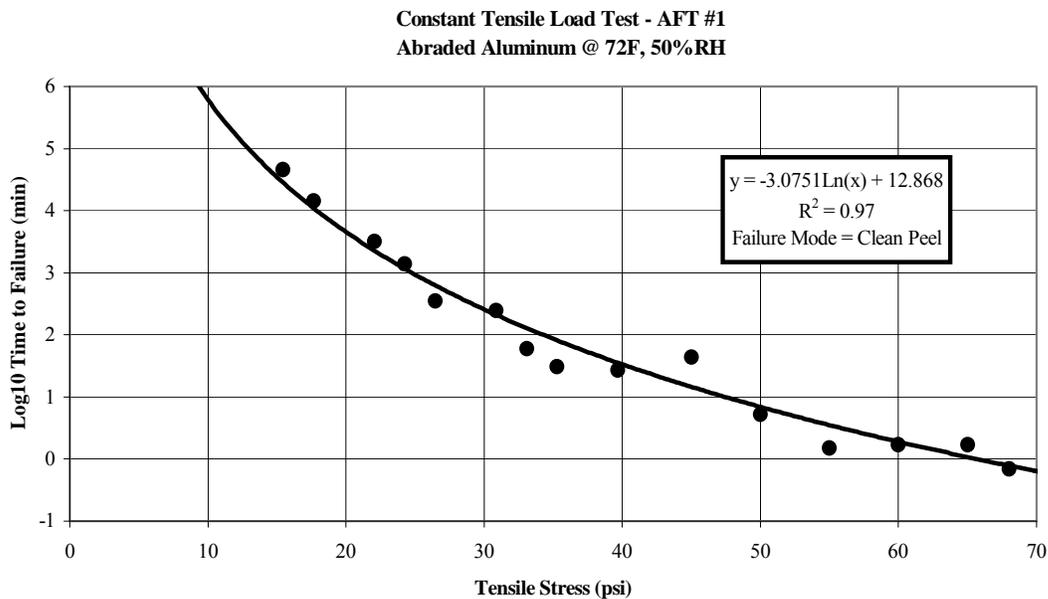


Figure 2. Constant Load Test Example - Tensile

Constant Shear Load Test - AFT #3  
Abraded Aluminum @ 72F, 50%RH

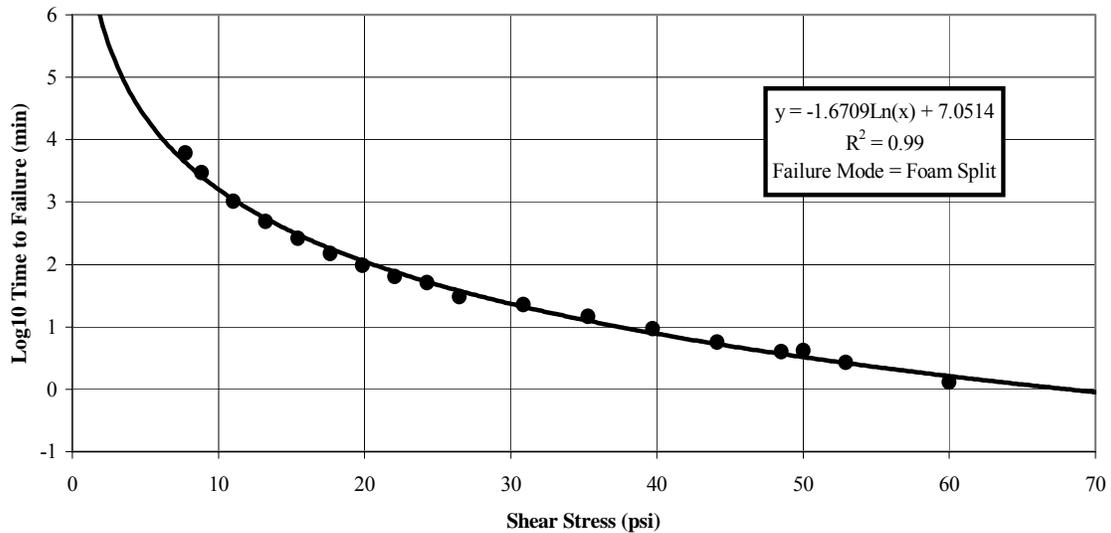


Figure 3. Constant Load Test Example - Shear

Although there was certainly some scatter in the test data, the results were generally well-behaved and exhibited excellent agreement with a logarithmic fit:

$$\log_{10}(\text{time}) = a - b \cdot \ln(\text{stress})$$

This equation provides the best characterization of acrylic foam tape performance in this test for several reasons: (1) the curve approaches the y-axis asymptotically, since adhesive tapes can hold an infinitesimal load for an infinite amount of time, (2) the curve does not approach the x-axis asymptotically, since failures can certainly occur in less than 1 minute at high enough loads, and (3) most importantly, a logarithmic equation provides the best fit of the data, with higher  $R^2$  values than any other regression. This equation is purely empirical and not based on any fundamental model or theory of acrylic foam tape debonding under stress.

The test was repeated in both tensile and shear for all three acrylic foam tapes, with the results provided in Figures 4 and 5 below.

**Constant Tensile Load Test  
Abraded Aluminum @ 72F, 50%RH**

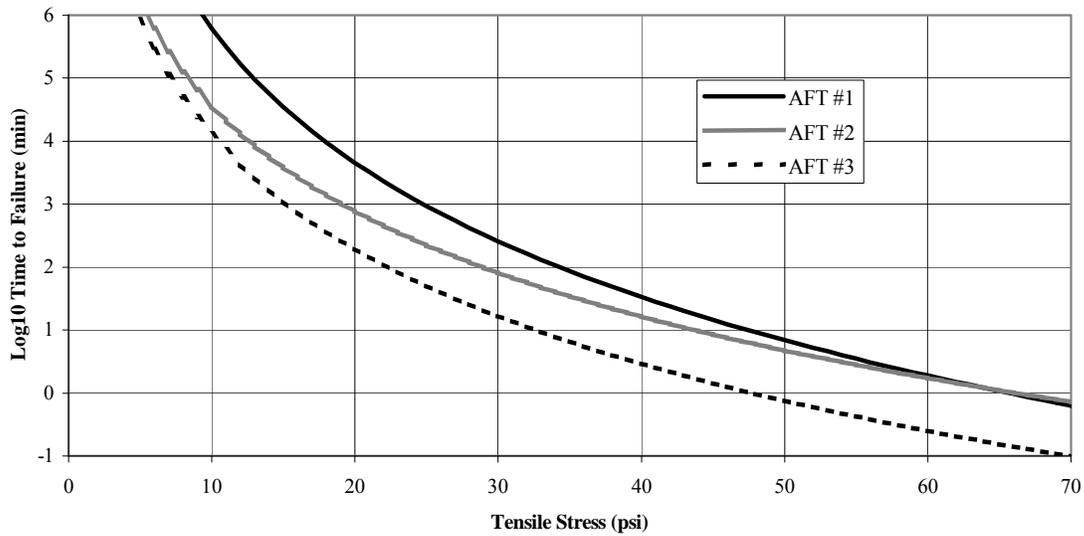


Figure 4. Constant Load Test Results - Tensile

**Constant Shear Load Test  
Abraded Aluminum @ 72F, 50%RH**

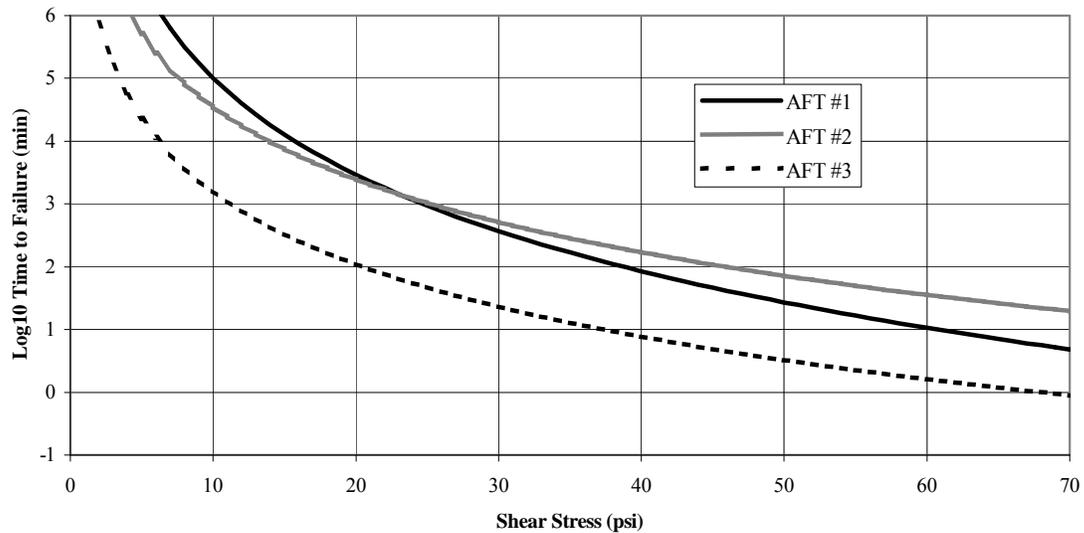


Figure 5. Constant Load Test Results - Shear

**Useful Design Criteria**

If the "ultimate" strength of an acrylic foam tape is defined when complete failure of the adhesive bond occurs, the "design" strength value that mechanical engineers need to perform their calculations must contain some safety factor to be certain that failure is never reached. In the design of architectural metal panels for exterior building cladding, the structural engineer will typically use a safety factor of 5 in the wind load calculations for the application of attaching face sheet to supporting frame. These wind load calculations are based on the highest 3-second wind gust from the 50-year worst storm for that geographical location. For example, the constant load test results for either AFT #1 or AFT #2 show an

ultimate tensile strength of around 60 psi for "dynamic" loads lasting seconds or minutes. This value already provides some conservatism when compared with the actual stress the tape could withstand during a 3-second wind gust, but this provides some margin to account for scatter in the test data and an expected slight decrease in performance if the wind event occurs at higher temperature or humidity conditions than existed during the testing. With a safety factor of 5, this ultimate strength translates to an allowable or design dynamic tensile strength of 12 psi. The engineer can then use this value to evaluate a panel attachment application under anticipated wind loads for a particular building project. The same thought process for AFT #3 would yield an ultimate strength of around 45 psi and a design strength of 9 psi for the same conditions. The lower strength of this acrylic foam tape means that either more bonding area would be required or the tape can only be used for less demanding industrial applications.

For long-term holding applications, engineers typically use a safety factor of 12 or more in their designs when using acrylic foam tapes. Therefore, the ultimate shear strength of around 3-5 psi for these three tapes under "static" loads lasting years or decades would get reduced to a design static shear strength of about 0.25 psi. The engineer can then use this value to evaluate the dead load holding power of an acrylic foam tape in a panel attachment application.

In addition to the common short-term "dynamic" and long-term "static" forces considered above, specific construction projects may have other types of loads that also need to be considered. For example, there may be diurnal forces that result from thermal expansion of components during the daytime and result in forces on the adhesive bond that act for a time period of hours. In some geographical locations, there may be snow loads on non-vertical architectural panels that exert forces on the bond over days, weeks, or even months. Regardless, the constant load test can be performed at the given orientation of the force on the adhesive bond, and a conservative value for the ultimate strength taken from the graph for the expected time period that force could exist. The application of a safety factor then yields a single, useful allowable strength value for the design engineer.

### **Alternative Constant Load Test**

The graphs and design values discussed thus far are all based on the time to complete bond failure. Depending on the particular industrial application, a different failure criterion may be desirable. For example, the design engineer may want to establish a limit of 100% strain on the acrylic foam tape to minimize creep, allow for unplanned differential movement, or provide an extra margin of conservatism against failure. The same constant load test used above could be performed again, measuring instead the time required to reach a certain amount of strain after applying the constant load. The logarithmic equation used above also provides the best fit of this test data. Figures 6 and 7 show representative results of strain over time in both tensile and shear mode under short time or "dynamic" constant loads. The design criteria would then be generated in the same fashion as before, but most likely using a smaller safety factor.

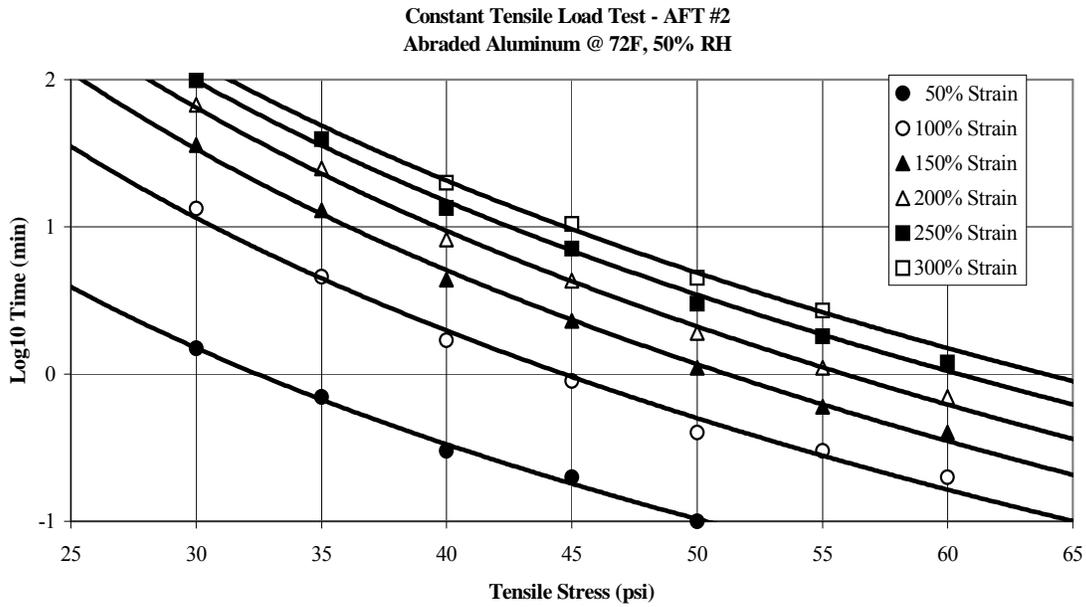


Figure 6. Constant Load Test Example - Tensile

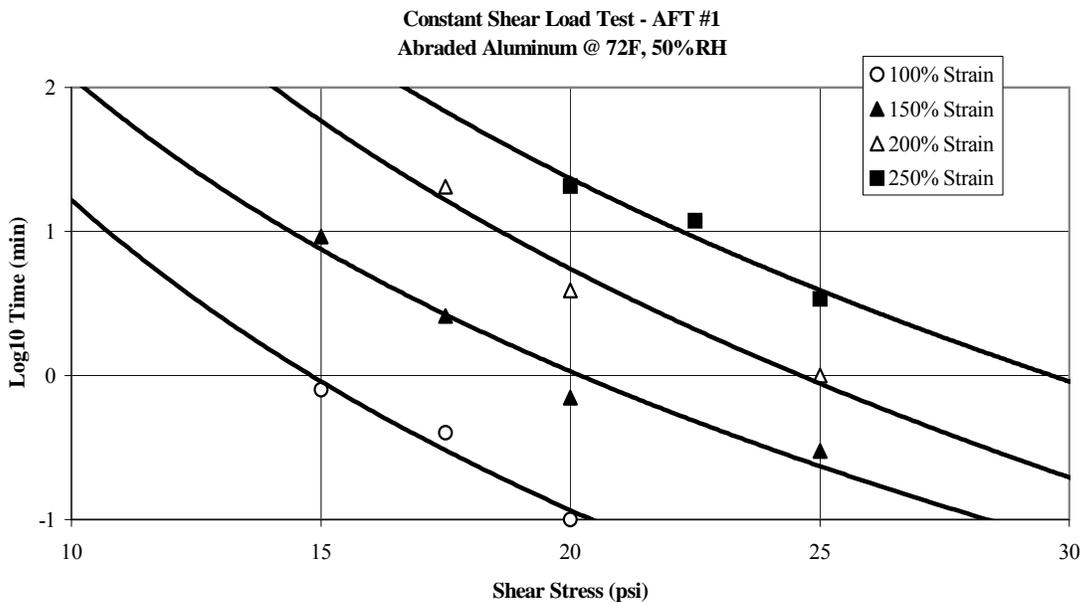


Figure 7. Constant Load Test Example - Shear

### A Word about Adhesion

In most of the tests performed here, the primary failure mode in either tensile or shear orientation was clean adhesive failure from the test substrate. Therefore, it is critical that the tape have sufficient surface adhesion to justify using the design parameters generated for the particular acrylic foam tape under consideration. Evaluation of each application should thus include peel adhesion tests to the actual materials used in the specific industrial project. This requirement becomes especially important when dealing with mechanical engineers who are educated to be more concerned with the internal strength of materials than with the effects of paints, coatings, and other surface conditions on adhesion.

The test surface for all of the experiments shown here was lightly abraded aluminum, cleaned with a tissue using a 50:50 mixture of isopropyl alcohol and water. All three acrylic foam tapes used in this study had a 90° peel removal force of at least 25 lb/in width to the aluminum surface, using a test speed of 12 in/min and a 5 mil thick aluminum foil for a test backing. Application of the design guidelines generated for these tapes could therefore be used in any project, as long as the adhesion to actual substrates met this minimum criterion. If the required adhesive removal force cannot be achieved, then a higher performance acrylic foam tape or additional surface preparation (such as abrasion or primer) must be considered to get the necessary adhesion.

### Validation: Comparison with Structural Silicone

Structural silicone sealants are widely accepted materials for commercial construction, commonly used for demanding applications such as the glazing of glass panels into curtain wall systems on skyscrapers. These materials have demonstrated their excellent performance and durability over the past 30 years and, therefore, provide an excellent material against which to compare the performance of acrylic foam tapes under similar tensile and shear test conditions. The constant load test was performed on a standard structural silicone sealant under the exact same test conditions, except that the silicone was allowed to cure at room temperature and 50% relative humidity for at least three weeks before testing. The results are shown in Figure 8 below.

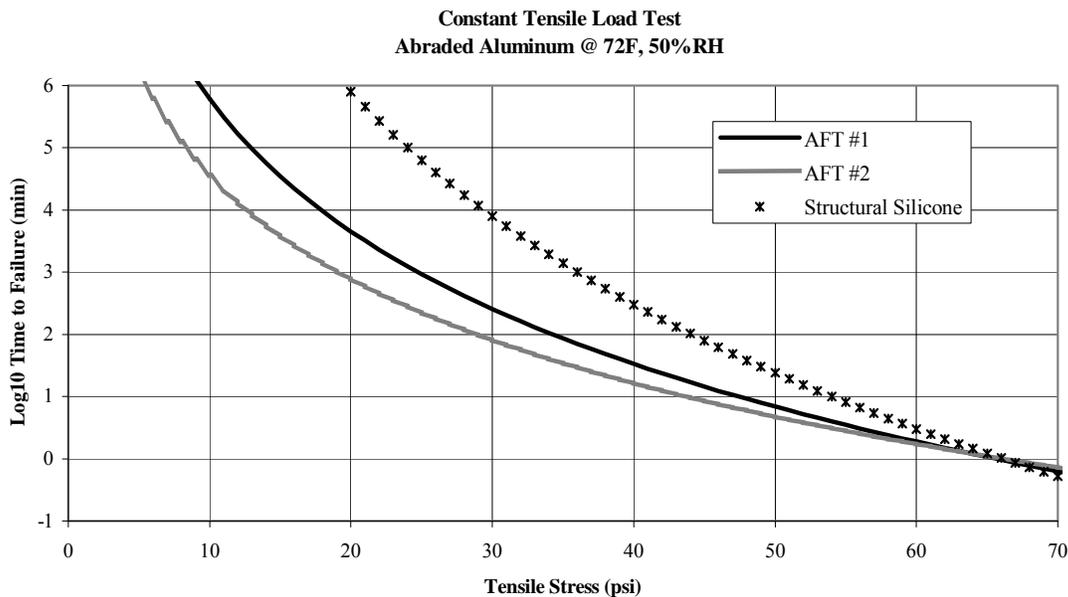


Figure 8. Constant Tensile Load Test - Comparison with Structural Silicone Sealant

Under dynamic loads such as high wind gusts, the forces generated on the adhesive bond between the panel and perimeter frame are applied for several seconds and then released. The test results show that two of the acrylic foam tapes tested here have equivalent performance to the silicone sealant under stresses applied on the order of seconds or minutes, indicating that the dynamic strengths of the two products are roughly equivalent. Under static loads such as long-term holding power, the forces generated on the adhesive bond between the panel and perimeter frame are designed to last for up to 50 years. The test results show that the acrylic foam tapes tested here have approximately 1/4 of the static

load capability compared to silicones under stresses applied on the order of years or decades, indicating that the static strengths of these tapes are about 1/4 of the static strength for silicone sealants. The design criteria developed earlier for these acrylic foam tapes reflect these comparisons with structural silicones, and still provide enough performance for most architectural metal panel applications.

This comparison was done using tensile forces, but a similar thought process can be followed for shear forces.

### **Validation: Mock-Up Tests**

To confirm that the allowable design strengths generated in this work were valid and conservative, a set of three full-size architectural panels constructed per Figure 1 were assembled using the three acrylic foam tapes studied here. The panels were subjected to both wind load tests and hurricane pressure cycling tests at Construction Research Laboratory (Miami, FL), a leading construction industry test facility.

The expected performance of the mock-up panels in these wind load tests was calculated using the design dynamic tensile strengths determined from the methodology described above for each acrylic foam tape. The panels made using AFT #1 and AFT #2 were designed to withstand an approximately 60 psf wind pressure (typical of high-rise buildings and equal to a sustained wind speed of 155 mph) using a design dynamic tensile strength of 12 psi for these tapes. The panel made using AFT #3 was designed to withstand an approximately 40 psf wind pressure (typical of low-rise buildings and equivalent to a 127 mph wind) using a design dynamic tensile strength of 9 psi for this tape. These calculations determined that a 1" wide strip of acrylic foam tape around the perimeter of the panel would provide sufficient performance for the application. Adequate adhesion of the tapes was also verified to be at least 25 lb/in width in 90° peel on the actual bare metal and painted metal surfaces.

The wind load tests were performed in accordance with the test method described in ASTM E330, which applies a uniform air pressure on the panels for a relatively long period of time for conservatism. The mock-up test results closely matched the expected performance. The panels made with AFT #1 and AFT #2 passed the wind load test at a 90 psf pressure, which met the usual requirement of surviving 150% of design pressure. The panel made with AFT #3 also passed its 150% design pressure value of 60 psf pressure, but then showed some cohesive failure at higher pressures, which was an expected result considering the lower tensile strength of this tape as indicated in the constant load tests.

The hurricane pressure cycling tests were performed in accordance with the test method described in ASTM E1886 using the applicable Dade County specification for architectural panels. This test resulted in 1,342 cycles on the panels, in the inward and outward directions, to a pressure sequence based on the design pressure of the panels. Again, the mock-up test results agreed with expected performance. The panels made with AFT #1 and AFT #2 passed the pressure cycling sequence using their design pressure of 60 psf, while the panel made with AFT #3 passed the test at 40 psf, but again showed signs of bond failure at higher pressure.

The results of these tests clearly illustrate the potential danger of using dynamic test results for designing acrylic foam tapes in industrial applications, because an overlap shear or normal tensile test does not accurately mimic what happens in real life when an adhesive bond is exposed to external forces. In both

mock-up panel tests, the panels assembled with AFT #3 failed at a lower test pressure. Yet in a dynamic normal tensile test, this tape provides the highest measured peak force of the three acrylic foam tapes.

## **Summary**

The viscoelastic nature of acrylic foam tapes presents a challenge to providing time-independent strength values that mechanical engineers can use to design industrial applications. The common dynamic overlap shear and normal tensile tests can be used to provide a relative comparison of tape performance, but they do not provide the right information for design calculations. Instead, a constant load test that better represents what actually happens to the adhesive bond under stress, along with an appropriate safety factor, can be used to generate simple, useful, and conservative values for tape performance that can be used in design calculations.

## **Acknowledgment**

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