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How Strong Is It? Measuring The Strength of Fix-It Epoxy Clay

By Todd Treichel

Introduction

While attending a recent high powered NAR launch I witnessed a level one certification attempt fail when an ejection delay was set too long causing the parachute and shock cord to separate from the rocket airframe. The good news was that the owner of the rocket was able to retrieve his Blue Tube built rocket and associated pieces, with a strong chance for repair and reattempt at certification the following day. Seeing that this particular NAR member belonged to a small gathering of people in close proximity to my viewing area (the usual lawn chair, truck tailgate down, my rockets, and toolbox), I was able to join in on the post-mortem discussion. The rocket was banged up and required reattachment of a fin and the shock cord. I do not know how the shock cord was attached originally but in an effort to help repair the rocket I recommended using FixIt Epoxy Clay and offered mine knowing it would be very easy to use and that there would be plenty of time for proper curing prior to the rescheduled certification attempt.

Much to my surprise my generosity was met with friendly skepticism and opinions about how two-part Super-Glue epoxy would be a better choice. One senior rocketeer engauged me in a debate about how two-part epoxies were far superior to clay and recommended using JB-Kwik Weld. I proceeded to voice the benefits of FixIt Epoxy clay (www.apogeerockets.com/Building_Supplies/Epoxy_Clay/FIXIT_Epoxy_Clay) and supported its strength by pointing at my own rockets where I've used FixIt Epoxy clay extensively. I surrendered in my debate because I did not have as many years of building and launching rockets as this gentleman and realized neither of us had any scientific basis for our positions. Dr. W. Edwards Deming, famous for his statistical process control techniques that helped post-war Japan become a world leader in the automobile market, was known for his phrases, "Show me the data" and "In God we trust, all others bring data" (Deming, 1982). I drove home from the launch thinking this topic would make a great student project and remembered the sign that hangs in my office, "One experiment is worth 1000 expert opinions." There were no students readily available for me to mentor a project with so I decided to conduct my own analysis in hopes of making a technical report or case study for other rocket builders to reference. I never doubted the strength of FixIt Epoxy clay but the results of this analysis should provide you with greater confidence in mastering the art of maximum adhesion.

Purpose

In the aerospace industry, engineering life into rocket designs cannot be done without good design data and/or proof that the design can sustain life within the harshest of user environments. The purpose of this analysis is to answer the question, "Which adhesive requires the greatest amount of force to break the bond?" I am fortunate enough to have access to some pretty cool test equipment and realize most rocket enthusiasts do not. The intent of this article is to provide the reader with some objective information about the strength of selected adhesives using scientific rationale in lieu of simple gut feeling.

In the field of material sciences, destructive testing in a laboratory is often performed to qualify materials based on investigation of potential risks associated with progressive and localized structural damage that occurs when materials are subjected to cycling loads or exposed to the impact of sudden stress. Tensile strength, for example, measures the force required to pull a material such as wire, structural bracket, fastener, or adhesive to the point where it breaks. According to the *Handbook of Adhesives* (Skeist, 1989), tensile strength of a material is the maximum amount of tensile stress that can be subjected to before failure in the form of breakage. Qualifying materials for use in aerospace structures and hardware is commonly done through analysis, followed by laboratory testing deemed destructive in nature. In other words, even if maximum stress limits are met and no destruction occurs in the laboratory, all samples are marked NOT FOR FLIGHT due to the potential weakening of material strength and typically disposed of in a controlled manner to avoid unintended use. Following

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good aerospace protocol, this analysis was administered in similar fashion where all selected samples were considered destructive and post-test materials were discarded accordingly.

Test Procedure

It is important to note that there is variation in everything we do. Sometimes a sample of one is acceptable when taste testing a store sample (not scientific sampling) or the cost of the sample is very high and you deem it necessary to glean as much information as you can with thorough analysis of one sample (in the engineering test world the cliché is called crash testing Cadillacs due to the high cost of destructive testing a single automobile). If you are an Apogee Components employee and it takes you about 25 minutes to drive to work every day, 25 minutes is a rough estimate and cannot be validated without proof. You decide to use a stopwatch and record your drive times, and you discover that you do not arrive each day in exactly 25 minutes. If you totaled the frequencies of your drive times you would find that random variation would cause you to arrive to work under 25 minutes on some days and over 25 minutes on other days. Figure 1 illustrates this hypothetical scenario showing central tendency where random events or process outcomes cluster around an average value. A measure of central tendency is a single value used to describe a set of data and in this case is the arithmetic mean. As long as the process of driving was performed in similar fashion, over all of the logged drive times, you will get a shape something like the one in Figure 1. If we plot a line over the histogram of tallied frequencies, we get a bell shaped curve. This is known as normal random variation, hence why statisticians and engineers call this curve a normal curve, theoretically representing a normal distribution. Now if there were road construction blocking traffic or an unforeseen traffic accident, this would not be normal and should be attributed to an assignable cause. No need to get into heavy statistics here but the main point is that if we were to conduct a tensile strength test on a sample of one and by chance it was at one of the tails of our normal distribution curve, we run the risk of making a misleading conclusion (much like an incorrect claim made by recording your drive to Apogee only once and it happened to fall on a 30 minute drive day). It is the average strength we are

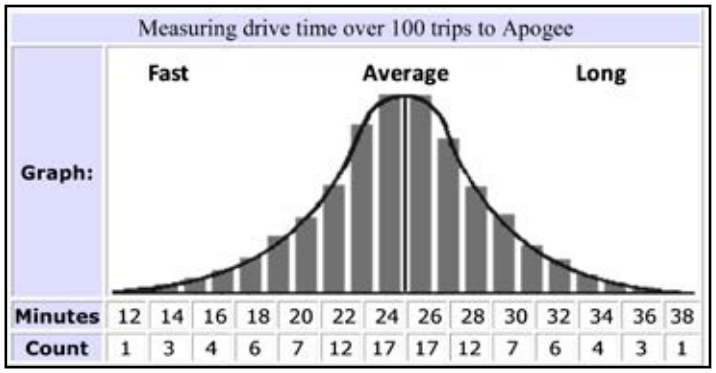

Figure 1. Frequency distribution for drive times to Apogee Components.

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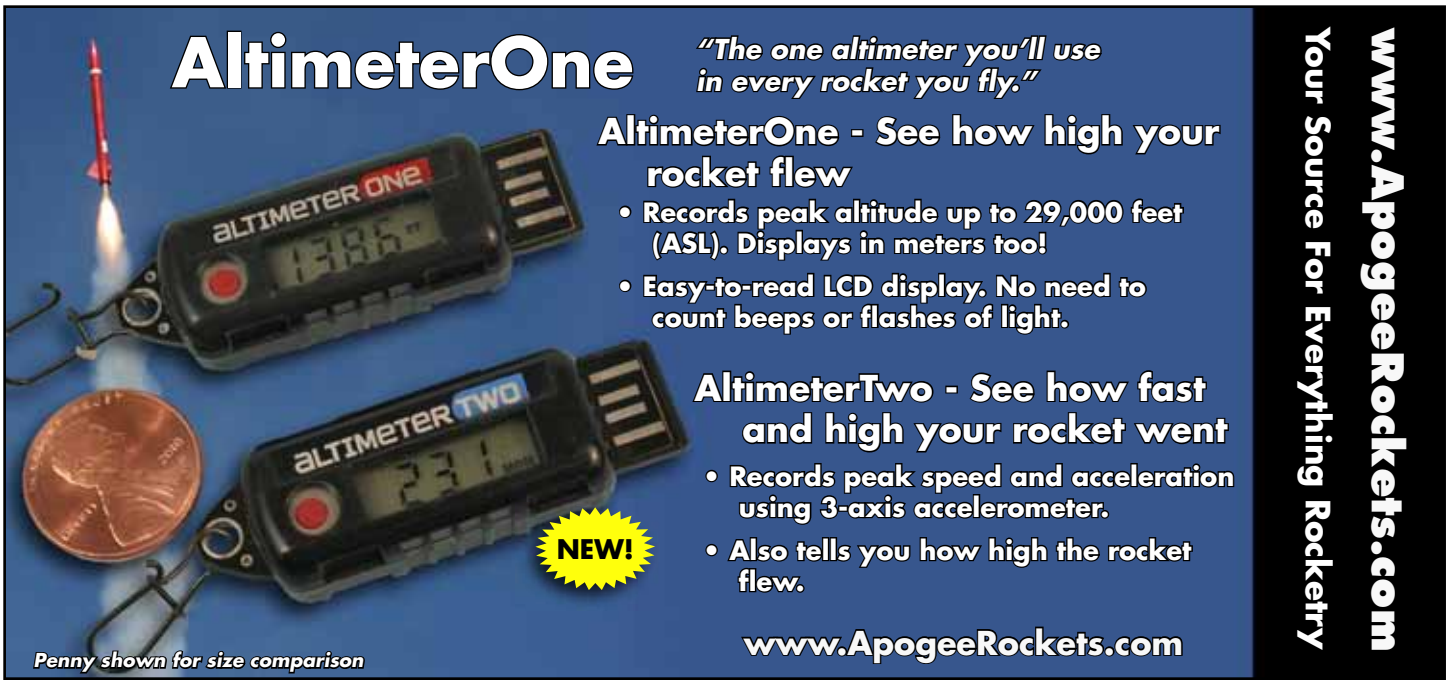

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interested in and the best way to build confidence in our analysis is to capture the normality of the adhesives under study and include enough samples to build confidence in making a claim about which one requires the greatest amount of force to break the adhesive bond.

The important thing to do when conducting a side-by-side analysis is to make every effort to keep the uncontrolled variables in the analysis as consistent and equal as possible. The reason for this is that we do not want to introduce any unintended bias which can skew your data and cause you to make incorrect conclusions or record a bad measurement resulting from an assignable cause (if the route to Apogee Components were redirected due to a traffic accident or road construction, you would not consider this data point as normal but one resulting from an assignable cause). In an effort to best simulate the original scenario that resulted in the research question, 1500 lb test strength braided Kevlar® cord (P/N 30327 at: www.ApogeeRockets.com/Building_Supplies/Parachutes_Recovery_Equipment/Shock_Cord/Kevlar_Cord_1500) and 98mm Blue Tube (P/N 10505 at: www.ApogeeRockets.com/Building_Supplies/Body_Tubes/Blue_Tubes/98mm_Blue_Tube) components were selected for building tensile strength test samples. Figure 2 illustrates pieces of Blue Tube that were cut into rectangular pieces and Kevlar cord cut and tied into loops capable of being tensile strength tested by means of hooking each sample and measuring the amount of force required to break the adhesive bond. All Blue Tube pieces were cleaned with isopropyl alcohol to assure an equally clean surface across all samples. Plastic syringes were used to consistently measure approximately two cubic centimeters of adhesive for each respective test sample (see

Figure 2. Components for sample preparation.

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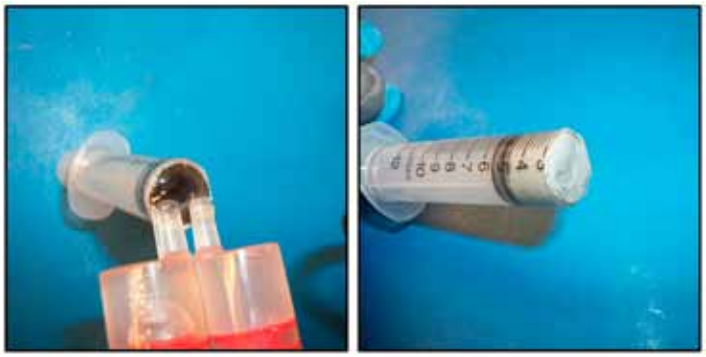

Figure 3. Adhesive measurement technique for sample application.

Figure). Test samples were prepared in groups of five for each of the three adhesives; Super-Glue 5 Minute epoxy, FixIt Epoxy Clay, and J-B Kwik. The preparation process was duplicated to obtain a total sample size of 10 pieces for each type of adhesive.

Samples were constructed, per the information previously discussed, to accommodate a pull test hook-type test fixture. A calibrated digital force gauge (see Figure 4) was used to perform destructive testing on the epoxy adhesives illustrated in Figure 4. All three epoxy brands come in two parts: resin and hardener. For each epoxy type the two parts were mixed in the precise ratio given in the manufacturer's instructions where one-to-one formulas were applicable for each. Mixing of respective resin and hardener combinations, whether viscous or clay composites, was conducted by means of constant stirring or kneading for a duration of 60 seconds. Upon completion of sample construction, all test specimens were allowed to cure for 24 hours in an effort to treat sample preparation equally. Figure 6 illustrates a close-up visual

Figure 5. Adhesive products used for tensile strength analysis.

Figure 4. Pull tester and tensile strength test configuration.

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for each representative adhesive sample prior to tensile strength testing.

Randomization is an important tool for removing experimental bias. Minor variations in operator techniques, changes in room temperature, and other uncontrolled factors, can introduce bias. Perhaps the operator gets better at handling samples toward the end of the test when compared to the beginning of the test. For this reason each piece of Blue Tube was numbered with a pencil and a random number generator used to place the samples in a randomized test order consisting of all adhesives under test. Cured samples were individually placed into the vice mounted on the test stand and the force gauge lowered such that the gauge hook could be positioned through the loop of the Kevlar shock cord as illustrated in Figure 6. The force gauge was moved, in an upward direction using an electronic motor built into the test apparatus, where the

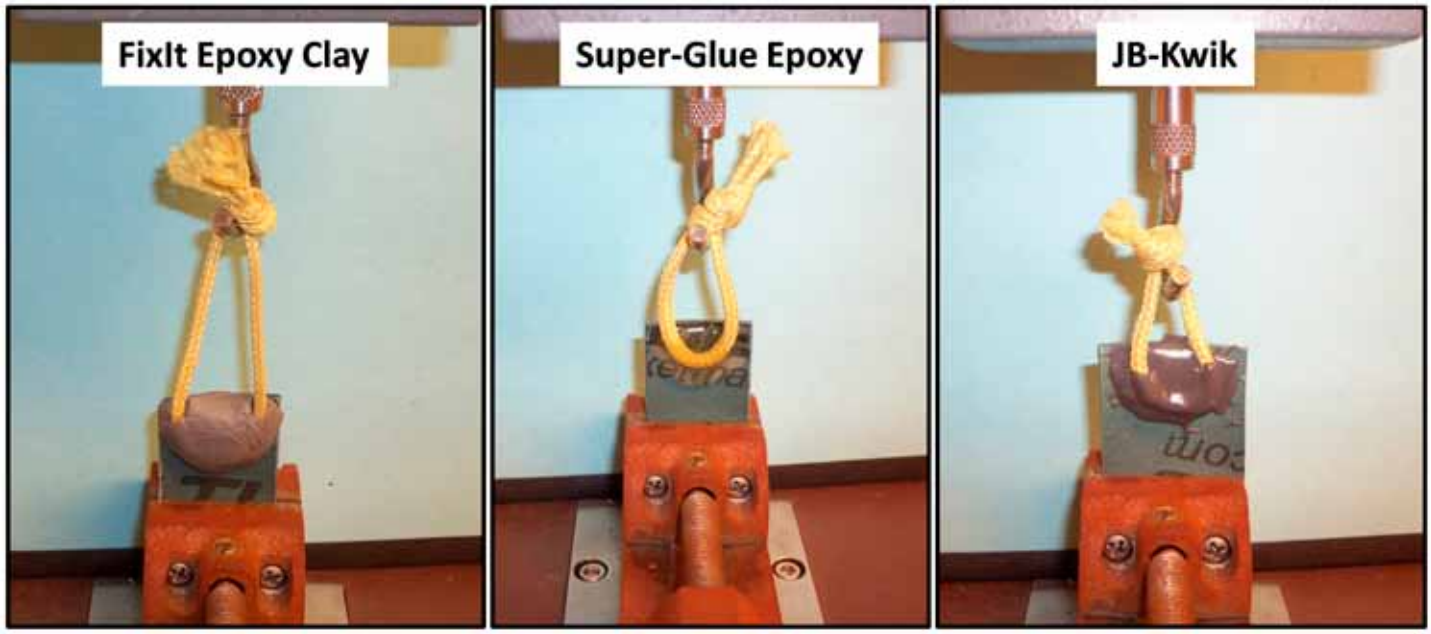

Figure 6. Close-up view of cured pretest samples.

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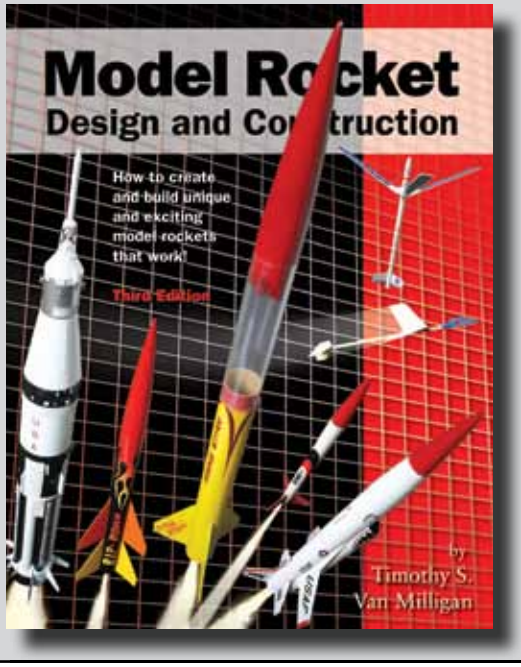

Model Rocket Design and Construction

By Timothy S. Van Milligan

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This massive, 328 page guidebook for serious rocket designers contains the most up-to-date information on creating unique and exciting models that really work. With 566 illustrations and 175 photos, it is the ultimate resource if you want to make rockets that will push the edge of the performance envelope. Because of the number of pictures, it is also a great gift to give to beginners to start them on their rocketry future.

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motor speed was maintained at a uniform speed of 10 mm/minute across all 30 samples. The resulting pull test data is provided in Table Table 1. It must be noted that Newtons would have been the scientific form of measure for force required to break the adhesive bond. However, the international system of measure was not used for the sake of the reader and to provide and easy relationship to US pounds.

Similar to building your rocket, an aerospace engineer must spend time performing basic descriptive statistics to establish a foundation for why a selected material is deemed suitable for use. Descriptive statistics provide a simple summary about analyzed samples and the observations that have been made. Table Table 2 illustrates the descriptive statistics for the tensile strength data collected using the calibrated force gauge. Looking at the mean values we can see that I am getting closer to putting some scientific evidence behind my launch-day claim that FixIt Epoxy clay would have been *just as strong* as the discussed alternatives. However, the data is indicating that FixIt Epoxy clay may in fact be *stronger* than the alternatives (which was not part of my original claim but certainly a point of interest).

FixIt	Super-Glue	JB-Kwik
104.1	66.3	61.8
100.7	79.9	51.6
85.2	90.9	51.7
72.9	48.8	59.0
71.8	59.3	43.2
79.6	85.0	48.7
113.7	43.1	66.5
83.7	60.2	58.1
65.8	70.1	48.5
94.8	64.4	60.2

Table 1. Tensile strength data recorded in pounds.

The minimum and maximum values are illustrated for the sake of knowing the highest and lowest observations. The problem with making decisions based on the range is that only the high and low values have been analyzed and a standard deviation accounts for the deviations within the range and provides the researcher with an indicator about how much variation or dispersion exists in proximity to the mean (or average). A low standard deviation number indicates that the normally random observations tend to be very close to the mean and a high standard deviation indicates that normally random observations are spread out over a longer distance from the mean. Thinking back to the normal curve used to illustrate our hypothetical drive

	FixIt	Super-Glue	JB-Kwik
Mean	87.2	66.8	54.9
Standard Deviation	15.64	15.22	7.26
Minimum	65.8	43.1	43.2
Maximum	113.7	90.9	66.5

Table 2. Descriptive statistics for tensile strength data.

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times to Apogee Components, the standard deviations illustrated in Table 2 indicate that JB-Kwik would have the least amount of variation within the respective normal distribution. However, remember our research question was looking to find which adhesive is the strongest. This is where our earlier discussion about normality and normal curves becomes useful.

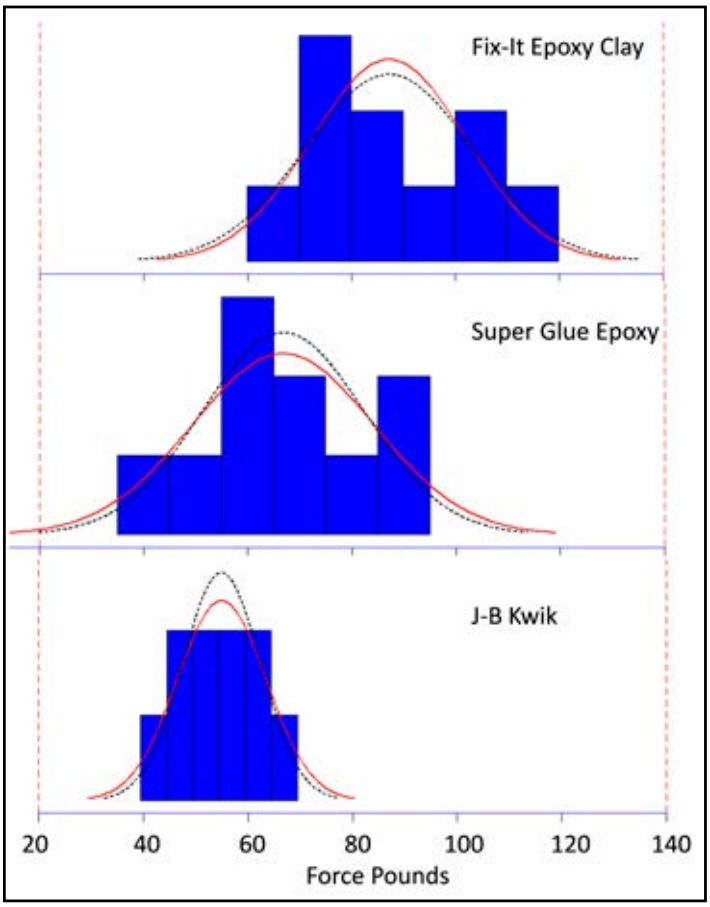

Figure 7. Summary of tensile strength data distributions.

Using statistical software the tensile strength data was plotted in Figure 7 to illustrate each data distribution for visual comparison. Due to the average of 54.9 pounds and the 7.26 standard deviation for JB-Kwik, we can make an engineering assumption that even at the strongest tail of the curve we are not going to have a high probability of achieving further pull test results above 66.5 pounds, so we will conclude that JB-Kwik is not the strongest adhesive to use for bonding Kevlar shock cord to Blue Tube. The casual observer might look at the remaining two data sets and conclude that it is a safe bet to select FixIt Epoxy clay.

Being rocket scientists, you may naturally view the top two histograms with some skepticism. You want to believe that FixIt Epoxy clay is stronger but you notice that there is plenty of overlap and the upper tail of the Super-Glue Epoxy distribution isn't that far away from the upper tail of the FixIt Epoxy clay. It is good that you are skeptical because there are engineers at NASA who get paid to analyze and challenge all claims made about newly selected materials and need to be convinced that your recommendation is worthy of being placed on to the NASA approved materials listing.

We are making a decision about selecting the strongest adhesive based on 10 samples for each adhesive. It is safe to say that if we tested 100 samples for each adhesive our confidence level would be higher in making a correct decision. There is always risk in using representative samples to make claims about an entire population of something under study. This is why we should conclude our analysis with conducting a hypothesis test to solidify our final decision and base our claim on data and not an emotional belief influenced by gut feel (or my excitement to say told you so in hindsight of my launch day epoxy debate). Hypothesis

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testing is used by scientist, engineers, and researchers to confirm or reject predictions about sampled data. A hypothesis is a statement about one or more populations of data. In other words, tensile strength data illustrated in Table 2 contains three populations of data where each adhesive under test is considered an individual population. We are interested in determining if indeed the FixIt Epoxy clay average tensile strength is stronger than that of Super-Glue Epoxy. In many cases data distributions can appear to be different, but based on probability the difference you may notice is not significant enough to rule out normal variation. In other words, the higher values observed in the FixIt Epoxy clay histogram could be simply due to random chance variation where in reality there is not real statistical difference.

Statistical Analysis

The purpose of hypothesis testing is to aid the decision maker with reaching a decision about whether to accept or reject such a statement based upon information gathered from sample data (Witte and Witte, 2010). A decision must be made about selecting one of two hypothesis where both the null and alternative hypothesis must be specified before a statistical test can be conducted. Based on the data distributions illustrated in Figure 7, we want to test the assumption that FixIt Epoxy clay is stronger. The two-sample *t*-test is a hypothesis test for answering questions about the mean where the data are collected from two random samples of independent observations, each from underlying normal distributions. As part of establishing our hypothesis, we need to state a null hypothesis and an alternative hypothesis for evaluation using the statistical data.

In order to test for significance we will consider the possibility of both distributions being equal (denoted by H_0 symbol). H_0 is also known as the null hypothesis which is where statistical evidence is provided that the difference between the two data sets is 0. The alternate hypothesis (denoted by the H_1 symbol) is the assumption that the two distributions are statistically significant and that a true difference exists between the two populations. Another way of stating the null hypothesis is that the difference between the mean of FixIt Epoxy Clay and the mean of Super-Glue Epoxy is zero and the alternate hypothesis is that the difference between the observed mean of FixIt Epoxy clay and the expected mean of Super-Glue Epoxy is not zero.

In this short analysis we are using statistics to prove (at the 95% confidence level, so there is a 5% chance we make an incorrect decision based on these data) that the two populations are significantly different. For the purpose of significance testing between the populations, the null and alternate hypotheses for this analysis have been constructed as follows:

The two sample *t*-test was selected as a suitable test of hypothesis for testing the difference between two population means. Mathematical symbols X-bar 1 and X-bar 2 are respectively the population means for the two populations from which the tensile-strength samples were drawn. The researcher must first pool the sample variances (standard deviations from Table 2) which can be accomplished by using the top formula and then calculate the *t*-statistic using the bottom formula illustrated in Figure 8.

$$S_P^2 = \frac{(n_1 - 1)S_1^2 + (n_2 - 1)\,S_2^2}{n_1 + n_2 - 2}$$

$$t = \frac{\bar{X}_1 - \bar{X}_2}{\sqrt{S_P^2\left(\frac{1}{n_1} + \frac{1}{n_2}\right)}}$$

$$\mathrm{df} = n_1 + n_2 - 2$$

Figure 8. Formula for pooled variances and two sample test of means.

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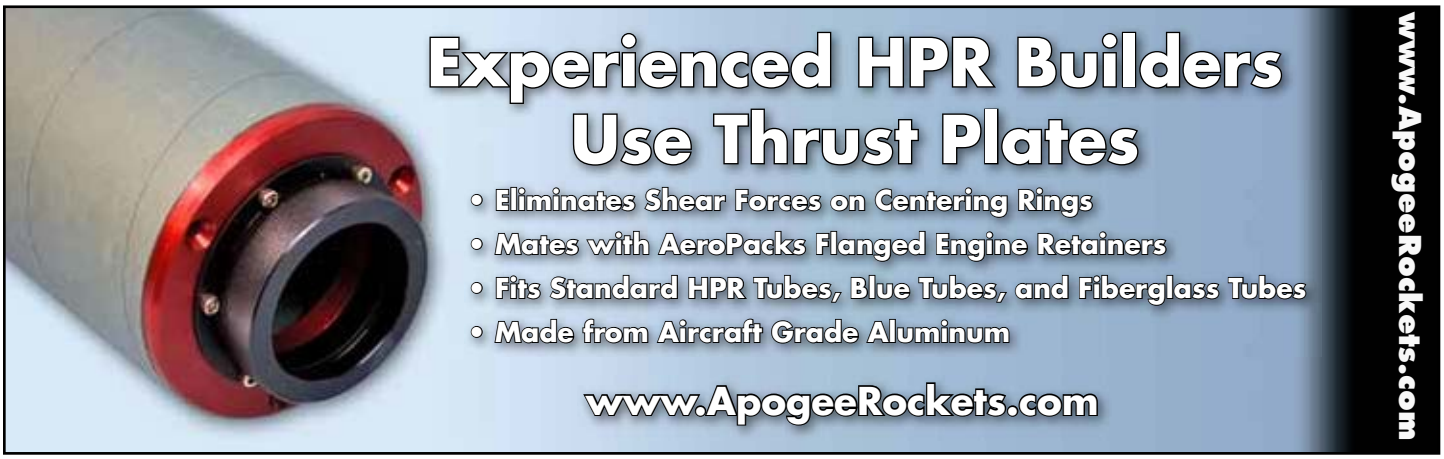

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Results

Having calculated the t-statistic, we need to compare the t-value with a standard table of t-values to determine whether the t-statistic reaches the threshold of statistical significance. For the statisticians out there the degrees of freedom calculation has been provided and is denoted by *df*. Using the critical value for *t*, (you will need to use the *t*-distribution table found in the appendix of your favorite statistics book) a critical value of 1.73 was obtained. Likewise, a calculated t-value of 11.62 was obtained per Figure 9. Since t_{calc} 11.62 > $t_{crit\ (\alpha.05)}$ 1.73, we reject the null hypothesis and conclude that there is a statistical difference between the two means.

$$S_P^2 = \frac{(9)15.6+(9)\ 15.2}{18} = 15.4$$

$$t = \frac{87.2 - 66.8}{\sqrt{15.4\,(.1+.1)}} = 11.62$$

$$\mathrm{df} = 10 + 10 - 2 = 18$$

Figure 9 . Calculations for two sample t-test of means.

Conclusion

Based on this analysis, we can make a hypothesis decision at the 95% confidence level, that the tensile strength mean for FixIt Epoxy clay is statistically significant and may conclude that greater tensile strength (or force pounds) is required to break the bond between Kevlar shock cord and Blue Tube material. There is sufficient statistical evidence to support the claim that FixIt Epoxy clay is the strongest choice, when compared to the alternatives discussed herein.

Based on these data, take advantage of being able to shape and sculpt your adhesive in lieu of working with a viscous adhesive that does not always hold the shape you desire. It is this writer's opinion that if you do not have FixIt Epoxy clay readily available, Super-Glue Epoxy and JB-Kwik brands are suitable choices assuming your application will not be exposed to the extreme tensile strengths recorded in this experiment. The intent of this analysis is to provide meaningful data to assist the rocket designer and builder with selecting an adhesive for use (a sort of consumer reports for rocket building). If you are attempting to repair, cast, or fabricate with epoxy resins, now you can use tensile strength data to support your FixIt Epoxy choice.

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About the Author

Todd Treichel is a Senior Systems Engineer at Orbital Technologies Corporation (ORBITEC) located in Madison, Wisconsin. He is a senior member of the American Institute for Aeronautics and Astronautics (AIAA). Todd currently serves as the AIAA Wisconsin section chairman and is involved in administering an AIAA Rocket Science for Educators program for K-12 teachers, promoting Science Technology Engineering and Mathematics (STEM) in curriculum development. His background also includes teaching statistics in the Wisconsin Technical College System and doing mission assurance and reliability work on military

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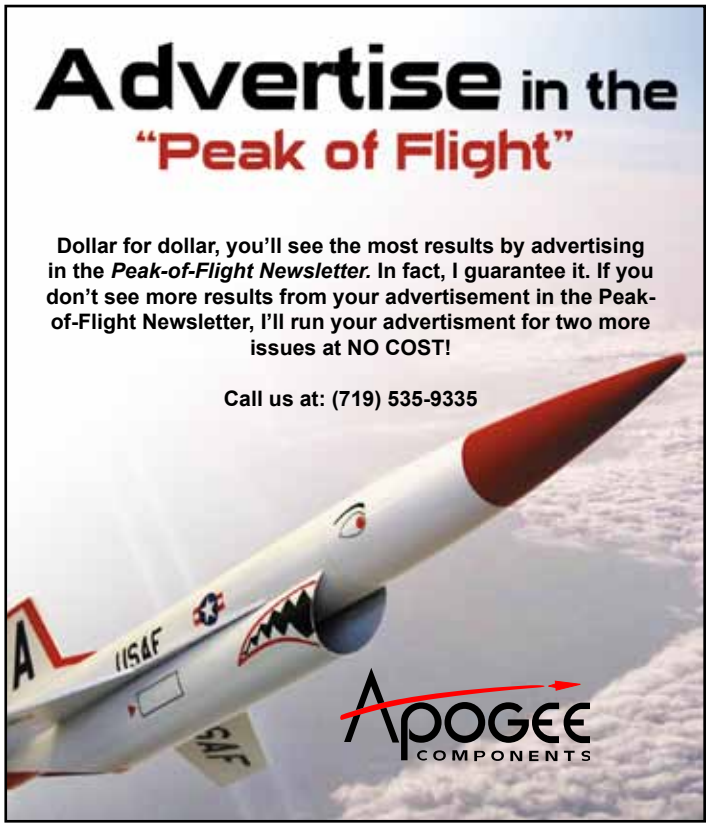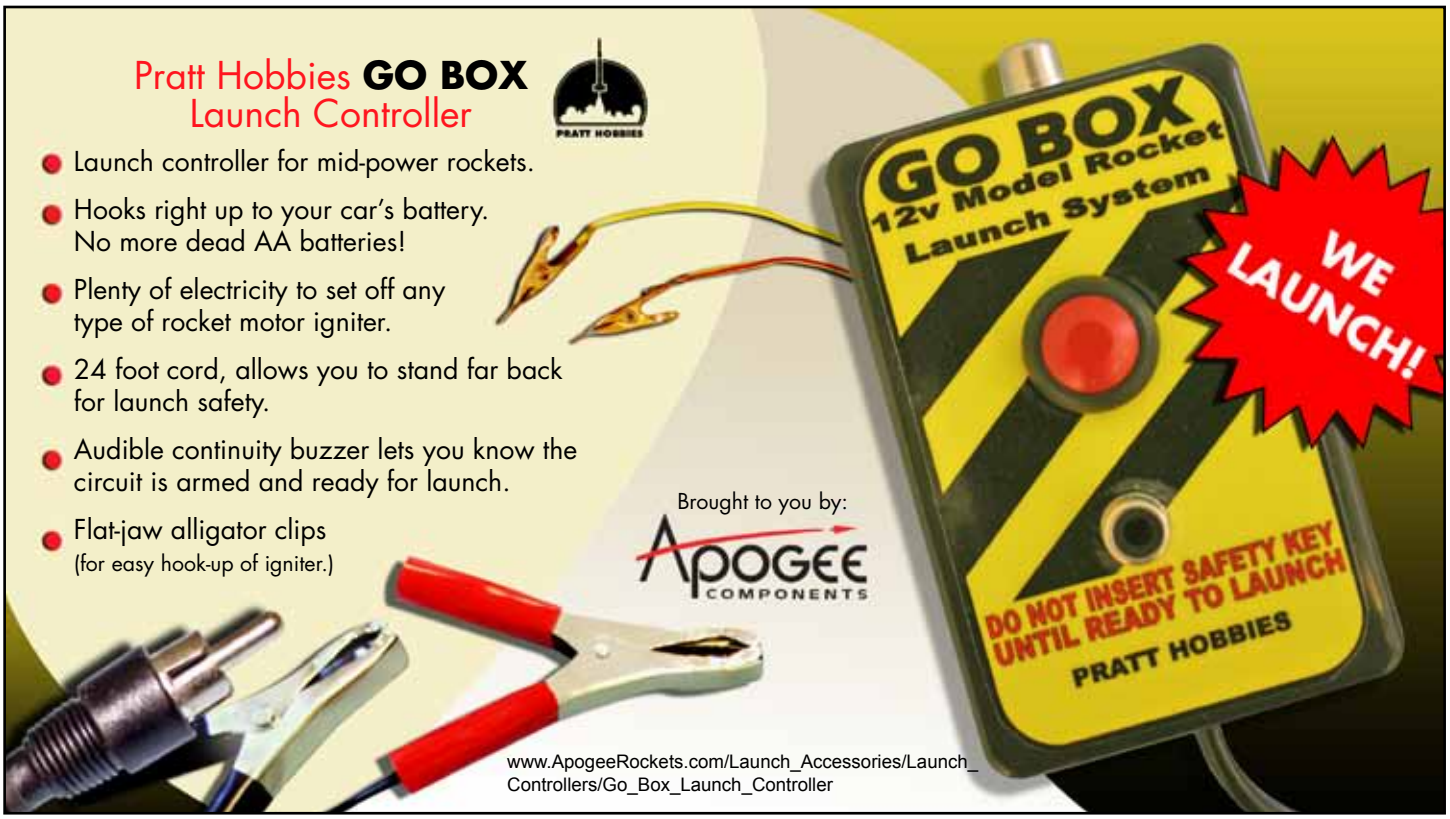
products, satellites, crew instrumentation, and propulsion space vehicles. Todd holds a BS and MS in manufacturing engineering and management and is level two certified with the National Association of Rocketry (NAR). Todd is married and has four children, two of which recently built and flown their first high powered rockets, and an eight year old who just finished building Aerotech's Initiator.