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AN INVESTIGATION OF PIN BEARING STRENGTH ON COMPOSITE MATERIALS

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About the Authors

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Jeremy Mostoller holds a B.S. degree in Engineering Science from Penn State University and has 8 years of experience in the area of design and analysis using composite materials. After receiving his degree, Jeremy worked as an associate engineer with Materials Sciences Corporation, where the majority of his workload was analysis of structural components using finite element methods. Jeremy joined Creative Pultrusions, Inc in 2006 as a product design engineer. Jeremy's primary responsibility is to work closely with the sales department to perform structural/composite engineering related functions.

Abstract

This paper aims to demonstrate the influence of various pin hole details and pin types to the ultimate and 4% hole elongation bearing strength values. This paper will demonstrate that the ASTM D 953 bearing strength test can be very misleading and that actual connection details should be mimicked in order to generate sound design values.

Introduction

The design of connections, within Fiberglass Reinforced Polymer (FRP) structures, is one of the most critical elements when performing structural design.

During the design process numerous failure modes must be scrutinized. Common practice is to design FRP structures such that pin bearing failure governs the connection design. This design methodology reduces the possibility of a catastrophic connection failure occurring instantaneously. Therefore, is it essential that designers be given sound pin bearing properties that account for the various factors affecting pin bearing strength.

This paper intends to point out some of the factors that affect pin bearing performance. The factors discussed in this paper include, the influence of pin diameter, clearance hole size, bolt threads in the bearing zone, and effects of failure definition. Designers can adequately force pin bearing failures in FRP connections by following recommended edge distance criteria in the design phase. The minimum edge distance values can be affected by the resin and the fiber volume fraction and type of fibers associated with the FRP components utilized in the connection. For the purposes of this paper the minimum edge distances were chosen in order to fail all of the test specimens in pin bearing mode.

Experimental Test Methods

A set of experiments were conducted on three different pultruded profiles with thicknesses of 0.25”, 0.30” and 0.5”. All three samples were pultruded with a standard fire retardant polyester resin with an E-glass reinforcement schedule. None of the samples were exposed to any type of accelerated aging condition and all samples were tested at ambient laboratory conditions. A series of pin bearing strength tests were conducted on the profiles with bolt diameters of ¼”, ½” and 5/8”. The ¼” pin bearing test was conducted utilizing the ASTM D 953 compression test method. The larger bolt tests were conducted utilizing a modified version of the ASTM D 953 compression protocol in order to accept larger diameter pins. The larger pin diameter required the specimen dimension also be adjusted to prevent other failure modes from occurring.

Testing was performed using two different compression load fixtures (Figure 1). The first fixture, used with 1/4" pins, required a specimen that was machined to a coupon dimension of 4 1/2" x .938". This fixture supported the entire face of the specimen. The support plates were brought into contact with the face of the specimen, but no torque was applied to the fixture bolts thus applying minimal initial transverse compression force on the specimen. The second fixture required a specimen size of 5.25" x 2.75" and was used for both the 1/2" and the 5/8" pins. This fixture has a 1" wide recess machined out of the specimen contact face such that no support was provide to the specimen in the area of the pin location. As with the first fixture no torque was applied to the fixture bolts.

Five specimens were run for each of the conditions investigated. Both 4% hole elongation and ultimate bearing strengths were recorded for each of the specimens. The following procedure was followed to conduct the tests.

1. Specimen was mounted into the fixture and the fixture bolts were tightened such that the face of the fixture contacted the specimen surface.
2. The specimen and fixture were placed in the test frame. An electronic dowel indicator was positioned under the specimen such that the arm of the indicator contacted the center of the bottom face of the specimen.
3. A 40lb load was applied to the specimen to seat the specimen onto the pin. At this point the dowel indicator reading was set to zero. The load was not reset to zero.
4. Load was applied at a constant rate of displacement.
5. The applied load was recorded when the dial indictor reading was 4% of the hole diameter, not 4% of the pin diameter. This value was used to calculate the bearing stress at 4% hole elongation
6. Load continued to be increased until a drop in load was detected. The peak load before the initial load drop was recorded and used to calculate the ultimate bearing strength.

Bearing strengths were calculated using the equation $\sigma_{Bearing} = P / dt$ where, $\sigma_{Bearing}$ is the bearing strength. P is the applied load at either 4% hole elongation or ultimate bearing load. d is the outer diameter of the pin, not the hole diameter. t is the thickness of the specimen being tested.

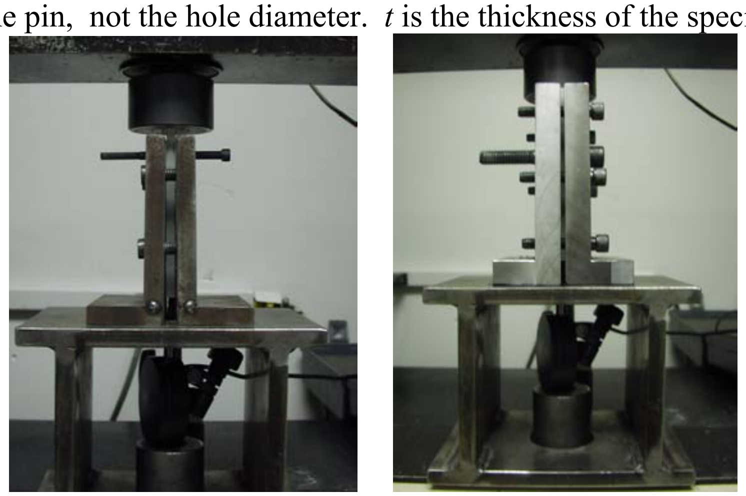

Figure 1. Experimental setup utilized for compression testing. Left is the fixture for the 1/4" pin. Right is the fixture for larger diameter pins.

Pin diameter effects

The pin diameter versus ultimate bearing strength tests were conducted utilizing a smooth pin in order to eliminate the affects of the bolt threads in the bearing zone. The hole diameters for this experiment matched the pin diameters. As depicted in Figure 2, as the pin diameter increases the bearing strength decreases. For the ¼" thick laminate the average strength decreased 7.0% between the ¼" pin and the ½" pin and 9.2% between the ¼" pin and the 5/8" pin. The 0.30" thick laminate produced the same trend. A reduction of bearing strength of 22.8% was observed between the ¼" and the ½" pin and a 28.9% bearing strength decrease was observed between the ¼" pin and the 5/8" pin. The ½" thick laminate produced a decrease in bearing strength of 6.7% between the ¼" and ½" pin and a 9.9% decrease between the ¼" and 5/8" pin.

A series of transverse bearing strength tests were conducted on 0.30" and ½" thick laminates utilizing the three pin sizes. The decrease in transverse bearing strength between the ¼" pin and the ½" and 5/8" pins on the .030" laminate were 30.6% and 38.1% respectively. Tests of the ½" laminate produced a 41.5% and 49.2% decrease in transverse bearing strength between the ¼" to ½" and 5/8" pins respectively.

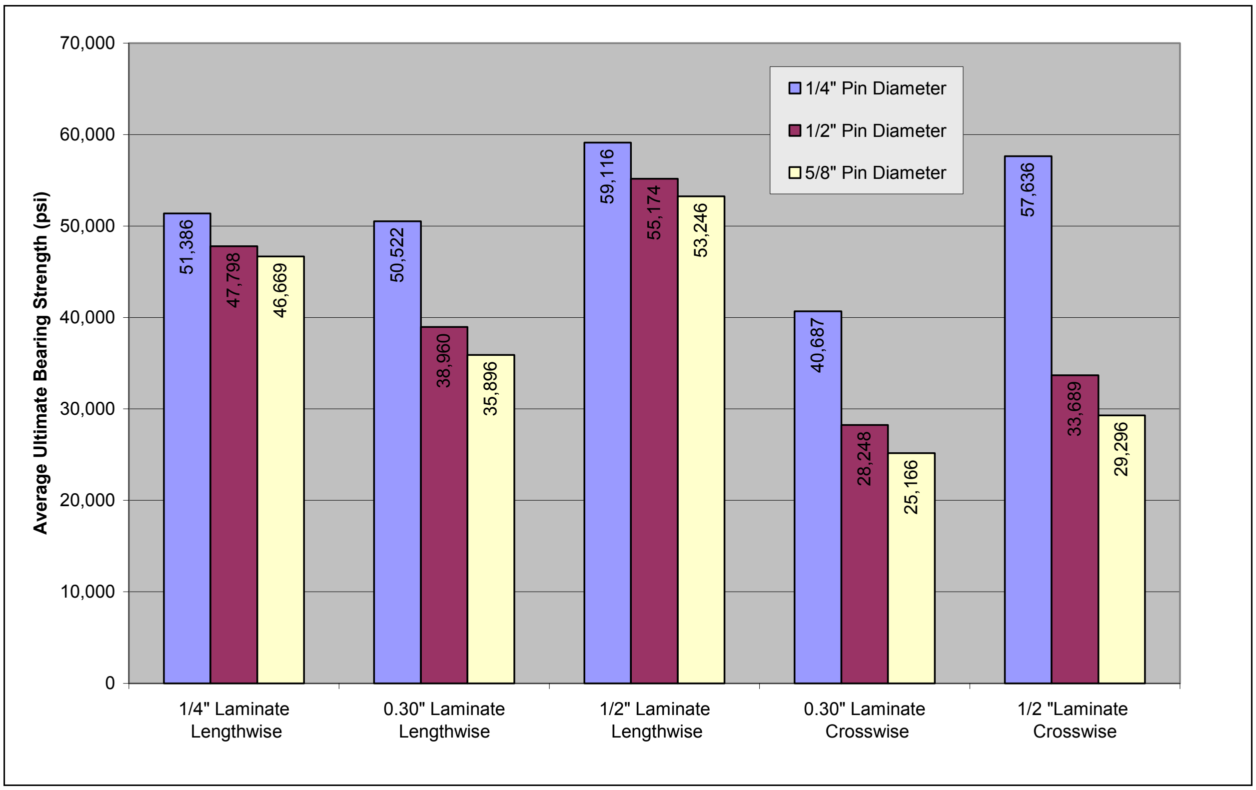

Figure 2. Chart of the average ultimate pin bearing strengths for various laminates and pin sizes.

Clearance hole effects

A set of experiments were conducted utilizing 0.30" and ½" laminates in order to investigate the influence of the hole diameter to pin diameter. Specifically, pin bearing strength tests were conducted on ¼", ½" and 5/8" smooth pins with oversized holes, measuring 5% and 1/16"over the diameter of the pins. The 0.30" laminate pin bearing strength results demonstrated that as the clearance hole size increased the bearing strength decreased. Figure 3 depicts this trend. The ¼" pin with a 5% oversized hole revealed a 9.3% decrease in pin bearing strength while the 1/16" oversized hole revealed a 25.8% reduction in strength as compared to the pin diameter being the same size as the drilled hole. The ½" pin bearing strength tests followed the same trend resulting in a 5.4% reduction for the 5% oversized hole and a 20.5% reduction in strength for the 1/16" oversized hole test. The 5/8" pin bearing strength test demonstrated the same trend resulting in a 1.5% reduction for the 5% oversized hole and 27.0% for the 1/16" oversized hole.

The same investigation was conducted on the ½" thick laminate. Each of the pin sizes produced results which were not characteristic of the previous test. The ¼" pin, with a 5% oversized hole, produced a reduction in bearing strength of 6.4% while the 1/16" oversized hole produced an increase in bearing strength of 2.9%. After reviewing the standard deviations of the five specimens for each set up, one can conclude that statistically the oversized hole had little influence on the ¼" pin test. The ½" pin test had a decrease in bearing strength of 34.5% comparing zero hole tolerance to the 5% hole tolerance and a decrease of only 25.3% when comparing the zero tolerance test to the 1/16" oversized hole. The 5/8" pin diameter results were very similar to the ½" results, producing a 34.3% and 27% respectively. Therefore, all tests of the ½" laminate produced higher values for the 1/16" clearance hole than for the 5% clearance hole which is the opposite of what was observed for the 0.30" laminate.

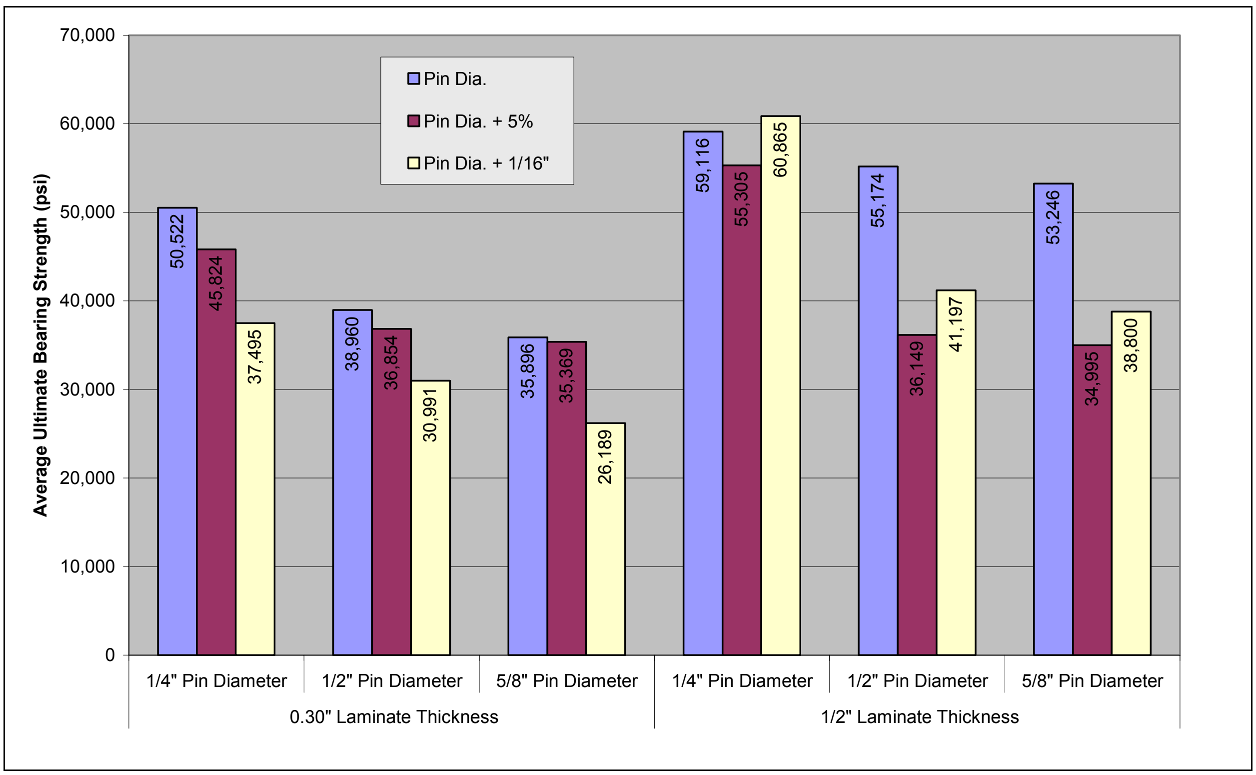

Figure 3. Chart of the average ultimate pin bearing strengths for various clearance hole sizes.

Bolt threads in the bearing zone

This set of experiments used grade 8 UNC bolts and located the threads in bearing area of the laminate. The same three laminates were investigated, however only the ½" and 5/8" diameter bolts were scrutinized. All of these experiments used a tight toleranced hole through the specimen.

As depicted in Figure 4, the smooth ½" pin exhibited a greater bearing capacity than the course threaded bolt of equal diameter, when tested in the ¼" laminate. The decrease in bearing strength was 36.8%. The 5/8" diameter pin and course thread bolt test conducted on the ¼" laminate demonstrated a reduction in bearing strength of 34.1%. The ½" diameter smooth pin to course thread bearing test on the 0.30" laminate resulted in a reduction of 24.1%, while the 5/8" smooth to thread comparison resulted in a 21.3% reduction in bearing strength. The same test conducted on the ½" laminate produced a 28.0% and 33.6% reduction in bearing strength when comparing smooth to course for the ½" and 5/8" fastener diameters.

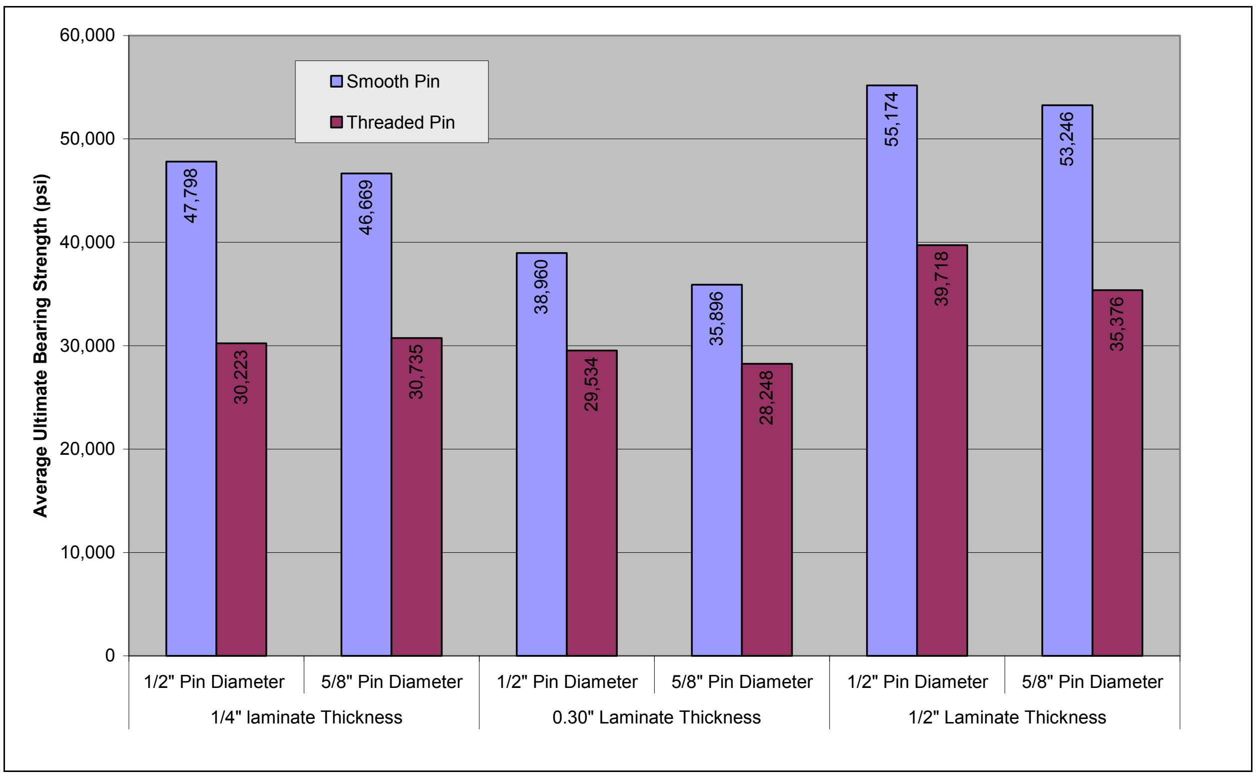

Figure 4. Chart of the average ultimate pin bearing strengths for the smooth and threaded pins.

<u>Failure definition</u>

Each of the tests performed for this series of experiments recorded both the ultimate bearing strength and the bearing strength based on the 4% hole elongation criteria. Figure 5 shows a sampling of results for the smooth pins without clearance holes. The data clearly shows that for larger pin diameters the difference between the two failure criteria become significantly less. For example, the ¼" laminate has a 4% hole bearing strength that is 27% that of the ultimate bearing strength for a ¼" pin. The same laminate has a 4% hole bearing strength that statistically equivalent to the ultimate bearing strength for a 5/8" pin. This same trend is observed for both the 0.30" and ½" laminate thicknesses.

The other significant trend of note is that as the laminate increases in thickness, ASTM D953 consistently produces a 4% hole bearing strength that is a smaller percentage of the ultimate bearing strength. The percentage of 4% hole elongation strength to ultimate bearing strength is 27.4%, 20.2%, and 8.1% for the ¼", 0.30", and ½" laminates, respectively. This indicates usage of a 4% hole elongation strength for a thick laminate will cause a structure to be grossly overdesigned as the factor of safety would be greater than 12.0. Typically engineers would use a factor of safety of 3.0 - 5.0 against ultimate bearing strength for typical structural applications.

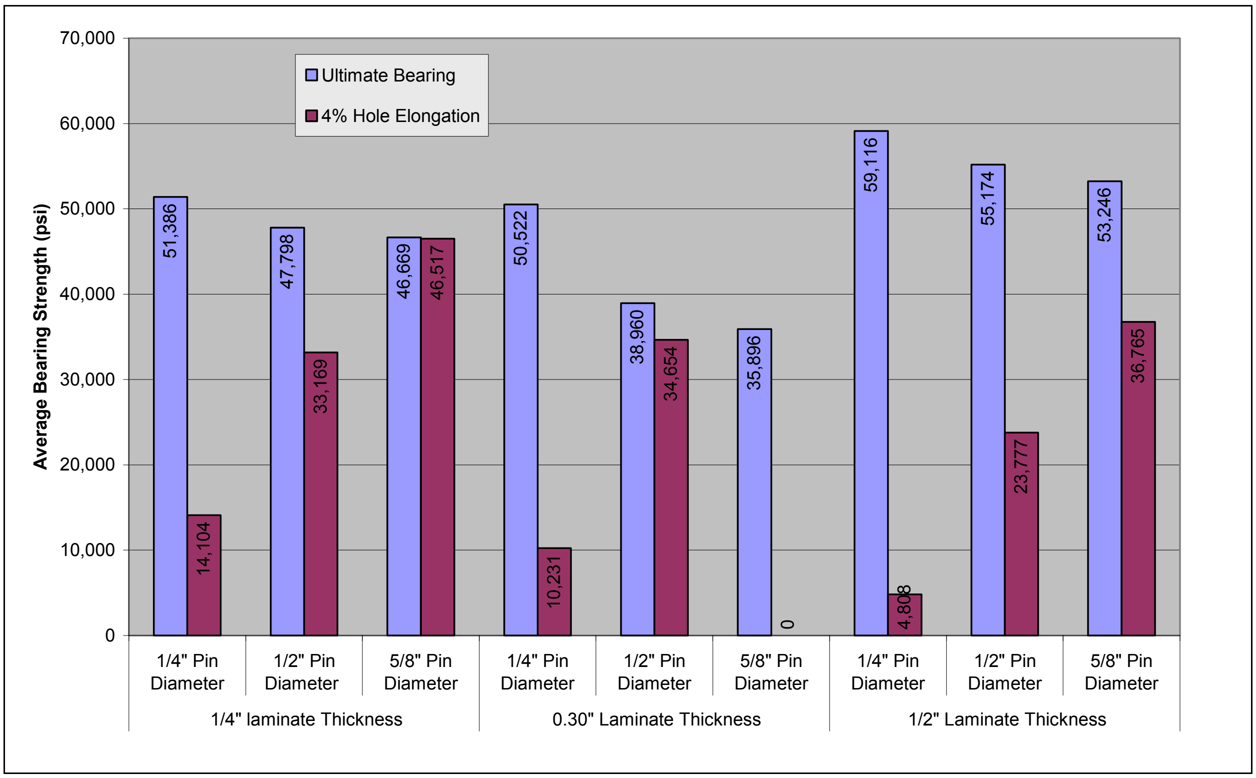

Figure 5. Chart comparing the ultimate bearing strength to the 4% hole elongation criteria. Note: a value of zero implies the parts achieved ultimate bearing strength prior to the 4% hole elongation.

Conclusion

The pin diameter versus ultimate bearing strength test findings demonstrated a consistent trend regardless of the laminate thickness or fiber architecture. The conclusive trend demonstrated that as the pin diameter increased, the bearing strength decreased regardless if the test was longitudinal or transverse pin bearing. The degree of decrease in pin bearing strength was also dependent upon the profile tested and the fiber architecture utilized in the profile.

The hole diameter to pin diameter comparison demonstrated in most of the cases examined that as the hole diameter for a given pin size increased the ultimate bearing strength decreased. The data developed on the 0.30" laminate demonstrated this tread and was very consistent.

However, the data developed on the ½” laminate thickness did not follow this same trend. This laminate when tested with the ¼” pin demonstrated that the hole diameter had little influence on the results. While the ½” pin and 5/8” pin results for the ½” laminate demonstrated a significant reduction in bearing strength for the 5% clearance hole but somewhat less of a reduction was observed for the 1/16” clearance hole. These set of tests make it apparent that the oversize hole diameter has a large influence on the structural efficiency of the connection. Therefore, further investigation into the laminate construction and test configuration is necessary to determine the root cause of these differing trends.

The bolt threads in the bearing zone versus a smooth pin demonstrated an average reduction in pin bearing strength of 29.6% across all three laminates.

Several trends were observed in comparing the 4% hole elongation failure criterion to the ultimate bearing strength failure criterion. The first trend observed is with increased bolt diameter the 4% hole elongation strength approaches the ultimate bearing strength. Also observed is that with increased laminate thickness the difference between 4% hole elongation and ultimate bearing strength becomes significantly larger. This can lead to the overdesign of structures.

Distinctive trends were observed throughout this series of tests. Further investigation is necessary to determine what influence combinations of the various configurations may have on the bearing strengths. Also of primary importance is how to account for these variants when performing structural design calculations.