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Multi-Station Tensile Creep Testing Facility

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ABSTRACT

A new water-cured fiberglass reinforced polymer known as Aquapreg®/Aquawrap® has been developed by Air Logistics Corp. of Pasadena, CA. This product has been used in several infrastructure applications, including column wrapping, aluminum pipe retrofits and repairs of in-place pipelines.

Thus, the environmental durability of this material system is of great importance. Various non-ambient conditions can have tremendous effects on the performance of a material. A study was undertaken with the University of Wyoming's Composite Materials Research Group to establish the ambient and non-ambient tensile creep response of the Aquapreg®/Aquawrap® system. An innovative multi-station creep test apparatus was fabricated to facilitate the timely testing of multiple test specimens at various environmental conditions, from room temperature and elevated temperatures to immersion in an alkaline solution.

KEY WORDS: Composite materials, Creep-rupture, Multi-station, Tensile creep, Testing equipment.

1. INTRODUCTION

Creep-rupture data is useful for designing structures and products that are subject to high stresses over long durations. The most useful data generating regimes require multiple specimens tested over a wide range of stresses and environmental conditions. This requires a considerable time investment to complete all the necessary testing. The current study required the determination of the long term tensile creep-rupture behavior of Air Logistic Corporations Aquapreg®/Aquawrap® fiberglass/urethane composite material. Air Logistics approached the Composite Materials Research Group (CMRG) at the University of Wyoming to perform this work due in part to the CMRG's experience with multi-station creep testing (1). Any test method used needed to conform to ASTM specifications and allow for the simultaneous testing of multiple specimens in order to compress the overall program duration as much as possible. To evaluate a wide range of end use conditions, the test program required testing at room temperature, 160ºF dry, and 140ºF while immersed in an alkaline solution. Loads were chosen to cause failure over a 10,000 hour time span. Twenty specimens were chosen, per test condition, to cover the time span. To reduce the overall time required for this program, three test frames were fabricated. Each frame, capable of testing 20 specimens, was dedicated to a single test condition.

2. TEST APPARATUS

2.1 Creep Frame Design Considerations The basic concept for the tensile creep apparatus consisted of a simple dead weight and lever system. Three creep frames were to be fabricated and each frame needed to accommodate multiple specimens. Limitations on laboratory floor space required a compact design for the creep frames. A large mechanical advantage in the leverage system was deemed preferable since it could utilize smaller dead weights further reducing the size of the apparatus. A system for gripping the tensile specimens under a variety of environmental conditions was also needed. The grips needed to be compact and inexpensive and the test environments needed to be stable over long durations of 10,000 hours.

2.2 Frame Design The lever system illustrated in Figure 1 served two goals. This arrangement allowed for a large mechanical advantage but kept a compact profile. The double lever arrangement produced a 110:1 load magnification while only being 38 inches long. This high lever ratio allowed for the use of convenient size dead weights of 20 to 28 pounds. The full load train consists of a series of links, levers, pivots and a turnbuckle. These elements allowed for ample adjustment in the system to maintain the levers in the optimal horizontal position. The various elements were sized to support a maximum load of 3000 pounds at the specimen. The actual test frame was equipped with twenty such levers, ten per side, enabling all twenty required tests to be situated on one frame. Figure 2 shows an end view of one such frame. The frame was fabricated with S6 x 12.5 structural steel beam. The frame did not twist or deflect when loaded with a full compliment of 20 specimens under creep loads ranging from 1500 to 2500 pounds.

2.3 Specimen Gripping Typically tensile test specimens are gripped using mechanical, pneumatic or hydraulically actuated wedge-acting grips. These grips require a large housing that can withstand the lateral forces produced by the wedge action. Such a gripping system would have been much too large and cost prohibitive for this project. Figure 3 illustrates the simple bolted grip used in this project. The gripping action is a combination of the bolt bearing strength of the tabbed specimen and the clamping force created by the two fasteners. The gripping effect was increased by aggressively grit blasting the surfaces in contact with the test specimen, thereby increasing the coefficient of friction of the grip surface. Fastener size and bolt torque were optimized experimentally via static tensile tests.

2.4 Specimen Fabrication Figure 4 details the tensile specimen geometry used for this program. Cured flat panels were provided to the test facility. The panels were tabbed with 0.062 inch thick G-10 fiberglass tabbing material. Straight-sided specimens were then cut from the panel and ground to 1.000 ± 0.003 inch width. The specimens were then dog-boned to their final geometry using a high speed router equipped with a water-cooled diamond faced cutting tool and a pattern cutting jig. The geometry chosen tapers the specimen sides with a 16 inch radius leaving a one inch long straight-sided gage section that is nominally 0.8 inch wide. The bolt-bearing holes were then drilled in the tabbed regions using a carbide drill bit. While the specimen preparation is tedious, it is imperative to the success of the testing program to have well–made, dimensionally consistent specimens.

2.5 Non-ambient Test Conditions The objective of this test program was to determine the tensile creep characteristics of the Aquapreg®/Aquawrap® material at room temperature as well as at hot dry, hot alkaline conditions.

2.5.1 Elevated Temperature Testing A method for heating all the specimens to a uniform temperature was needed. Individual heaters with controllers were ruled too expensive. Therefore a single heater and controller were used to heat an insulated chamber surrounding all the specimens. A circulating air fan and a system of diffusers were used to maintain uniform temperature within the chamber. Refer to Figure 1 to view details of the environmental chamber. Specimens were tested at 160°F for the hot dry condition.

2.5.2 Liquid Immersion Conditions Caustic liquid was held in contact with the test specimen using an aluminum cup and cast silicon arrangement. Figure 5 shows a schematic of the setup. A buffered pH 10 solution was used as the caustic liquid. The cupped specimens were tested at 140ºF using the elevated temperature arrangement described above.

2.6 Test Frame Operation Subsequent to specimen fabrication the operation of the creep frame requires several steps. The main steps include assembling the grips, choosing the weights, calibrating the loads, loading the weights and recording time to failures. Each station of the creep frame is assigned a specimen. All subsequent operations involving that specimen are unique to that station. Accurate records are required to track specimen location, creep load, dead weight load, and time to failure

2.6.1 Grip Assembly The grips shown in Figure 3 were bolted to the test specimen. The bolts were torqued to 60 in-lbs. This was found to be the minimum bolt torque to provide enough clamping force to prevent bearing failure around the bolt holes.

2.6.2 Choosing Weights Prior to starting the long term creep tests a load profile for twenty specimens was developed for the material. The goal of the profile was the generation of creep-ruptures distributed over a time range of 10 to 10,000 hours. This profile, as well as the nominal mechanical advantages of the lever arms, was used to estimate the size of the deadweights. Specimens were not interchangeable. A specimen was assigned to a specific station on the creep frame and subsequent dead weight determinations were made for that station.

2.6.3 Load Calibration Once a desired load was determined for a specimen, the appropriate dead weight was fabricated. A calibrated load cell was positioned in the load train in place of the test specimen. The assigned dead weight was applied to the station and the resulting creep load was measured. The turnbuckle in the load train was adjusted to accommodate for the elastic deformation of the levers and connecting elements in the load train. The lever was adjusted to horizontal. The dead weight was adjusted by trimming or adding weight to achieve the desired creep load for that station. The dead weight and load cell were then removed and the specimen with grip assembly was pinned in place.

2.6.4 Initiating the Creep Test Once all the specimens were in place, the dead weights were returned to their assigned station marking the start of the creep test. At this time further adjustments to the turnbuckle were made to bring the main lever back to horizontal. For non-ambient test conditions, specimen temperature was allowed to equilibrate before applying the dead weights. Datasheets were maintained that recorded the specimen identity, location on the apparatus, calibrated load, dead weight size, start date and time as well as the failure date and time. Specimens were closely monitored the first 20 hours, and then checked daily thereafter.

3. EXPERIMENTAL

3.1 Material The composite material selected for the initial series of tests was Air Logistics Aquapreg®/Aquawrap® 22-71. This material system uses an E-glass woven tape fabric impregnated with a water cured urethane resin. The fabric has a weight of eleven ounces per square yard and has a warp to fill ratio of 74/26. The ASTM D 3039 (2) average tensile strength of this composite is 71.7 ksi and exhibits a nominal strength per ply per inch of width of 801 pounds.

The panels used in this program were five plies thick. This thickness provided a good compromise between gripping force, load transfer to the composite and a sufficient number of plies to simulate an end-use product. Air Logistics Corporation of Pasadena, California fabricated the cured panels. The panels measured 10 inch by 10 inch. Nine specimens were fabricated from each panel.

3.2 Load Selection The load selection process was one of trial and error. ASTM D 2990 and 2992 (3,4) require a distribution of loads to produce a minimum number of failures at specified time intervals, which will insure that there is sufficient data for interpretation. The data can then be extrapolated to determine the load carrying capacity of the composite material for time periods up to 25 years based on a 10,000 hour test.

For this project the initial load selection was too high and many failures occurred during the first few hours of the test. This early data was analyzed and a revised set of loads for the balance of the test was developed. After the first 1000 hours of creep testing the failure distribution was analyzed again and it was apparent that some of the loads chosen were too low precluding rupture in less than 10,000 hours. This testing also revealed significant gaps in the data. Extra tests were run using loads that would produce ruptures during the intervals previously missed.

4. RESULTS

4.1 Room Temperature The results of the room temperature testing are shown in Figure 6. When plotted on a semi-log graph the failures followed the traditional straight line expectation with only a minimal amount of deviation. The results so far project a long term (25 year) load carrying capacity of this material in excess of 50% of its static strength.

4.2 Elevated Temperature This testing was started a while after the room temperature tests began and are ongoing. The initial results of the elevated temperature testing at 160^o F are shown in Figure 7. These results indicate the need for additional failures between 1 and 200 hours and beyond 2000 hours. Preliminary results project a long term (25 year) load carrying capacity of this material to be 46% of its static room temperature strength. Additional data points are required to complete this test.

4.3 Hot Alkaline Soak These tests were conducted at a temperature of 140^o F and in a buffered pH 10 solution. The results of these tests are shown in Figure 8. These results demonstrate that the composite requires a protective coating to perform well in a high alkaline environment.

5. DISCUSSION

5.1 Test Apparatus and Coupon Design The initial results indicate that the combination of the multi-station test apparatus design coupled with a typical coupon and a simple grip design provided meaningful results. The specimen geometry was successful in that all specimen failures occurred with in the specimen gage section. The creep apparatus proved effective and relatively inexpensive to construct and operate. The double lever concept worked well and allowed the use of conveniently sized dead weights. The fluid container system used to maintain the alkaline soak also worked well. The tensile creep apparatus fulfilled the basic functions for which it was designed. Multiple specimens were simultaneously tested over a range of tensile loads and a variety of environmental conditions. Allowing for the generation of a wide variety of data in a timely manner.

The drawbacks experienced with the apparatus were namely the amount of time needed to load 20 specimens. The simple grip design required the extra specimen fabrication step of drilling holes. Additional time was also needed to assemble the multiple parts of the grip and bolt these parts together. The amount of time required was significantly longer than that needed to grip a specimen when performing a static test using a test machine equipped with hydraulically actuated wedge-acting grips. But, the total time spent loading specimens was insignificant in comparison to the total duration of the creep tests. The time needed to prepare for the non-ambient conditions was comparable to that typically required of static testing.

The experience obtained while determining the necessary dead weight loads using the calibrated load cell indicated a variation in the resulting creep loads of 4 percent. This very small variation helped validate the test apparatus design and reinforced confidence in the creep test results. The apparatus achieved good thermal distribution throughout the insulated test chamber during the elevated temperature tests.

5.2 Experimental Results Efforts to compress the total time spent collecting creep-rupture data were undermined by the difficulties inherent in predicting creep response under high loads. For this project it was necessary to adopt an iterative approach to determine the loads that best described the creep-rupture response over the 10,000 hours. In general, the creep-rupture testing provided valuable information about the durability of the Aquapreg®/Aquawrap® system. The room temperature and dry heat results in terms of long term load carrying capacity are excellent. Traditional glass epoxy systems typically provide 20% to 30% of the ASTM D 3039 coupon test load. The use of the unique urethane resin system provided this excellent result. The reason for this improved performance is the ductility of the urethane resin system. Epoxy systems tend to suffer micro-cracks under long-term loads and the urethane system used in this series of tests did not. The same performance improvement has also been demonstrated in cyclical load testing. The performance in the high pH environment demonstrated the need for coating of the cured composite.

6. CONCLUSIONS

6.1 Conclusions The apparatus, coupon and its grip design provided an effective low cost design approach to the creep test problem. The E-glass urethane resin combination test results proved its excellent long-term load bearing capability.

7. REFERENCES

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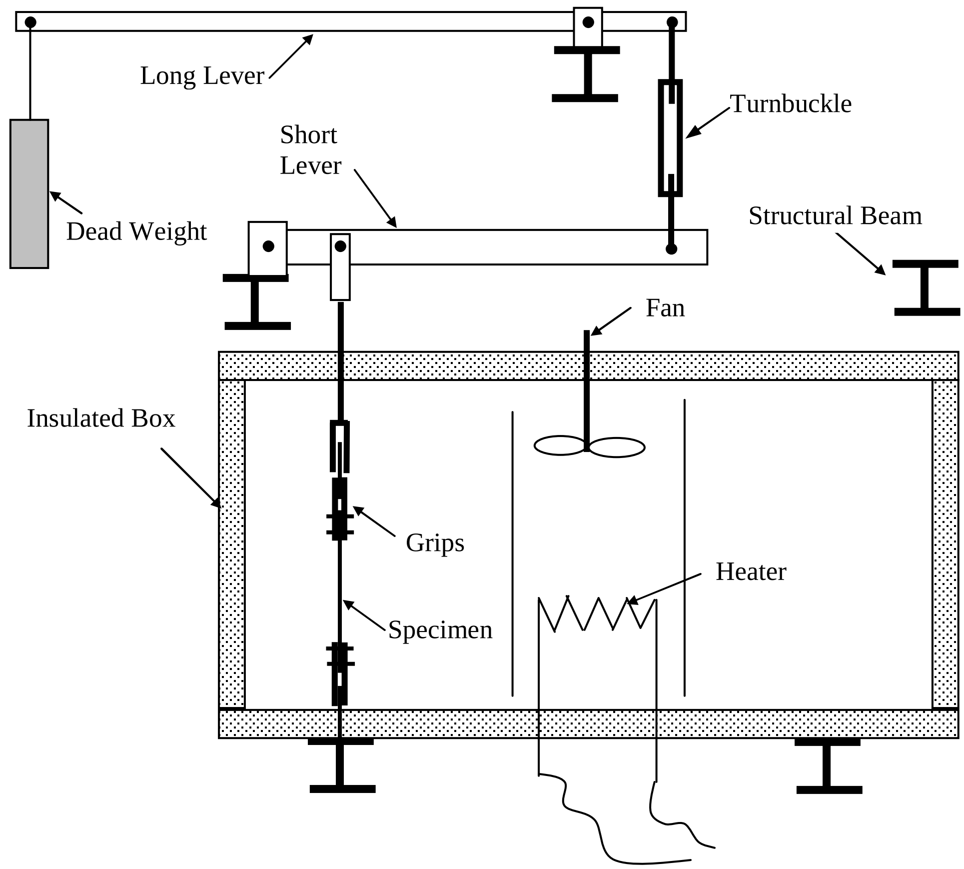

Figure 1. Multi-station Tensile Creep Apparatus Schematic

Figure 2. Multi-Station Tensile Creep Apparatus

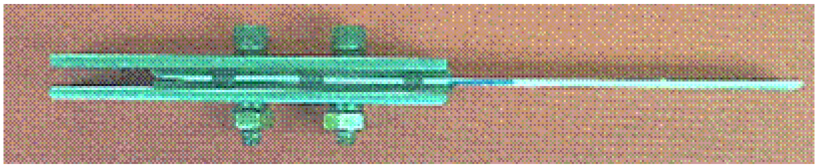

Figure 3. Bolted Grip Assembly

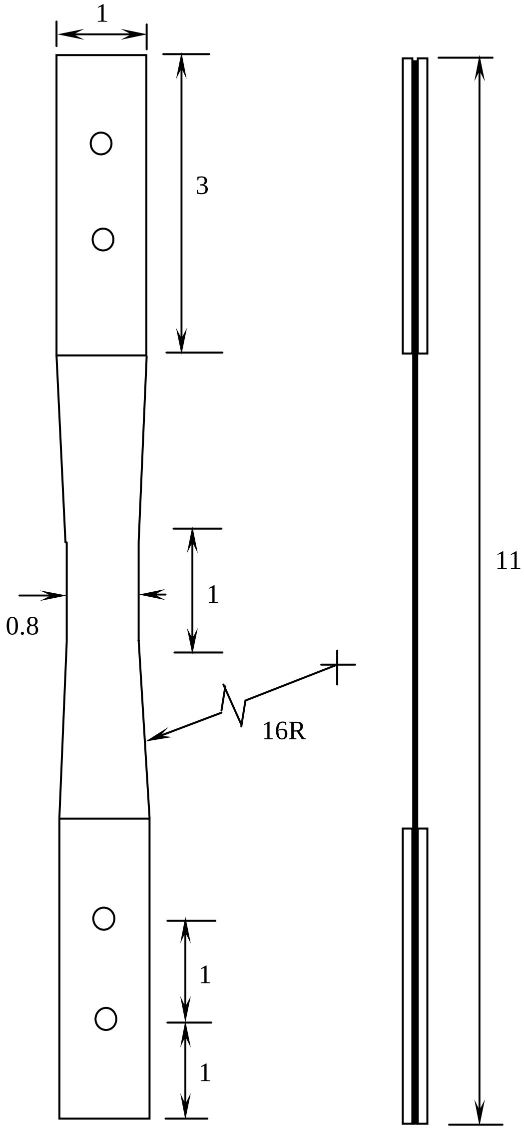

Figure 4. Tensile Specimen Geometry (Dimensions in Inches)

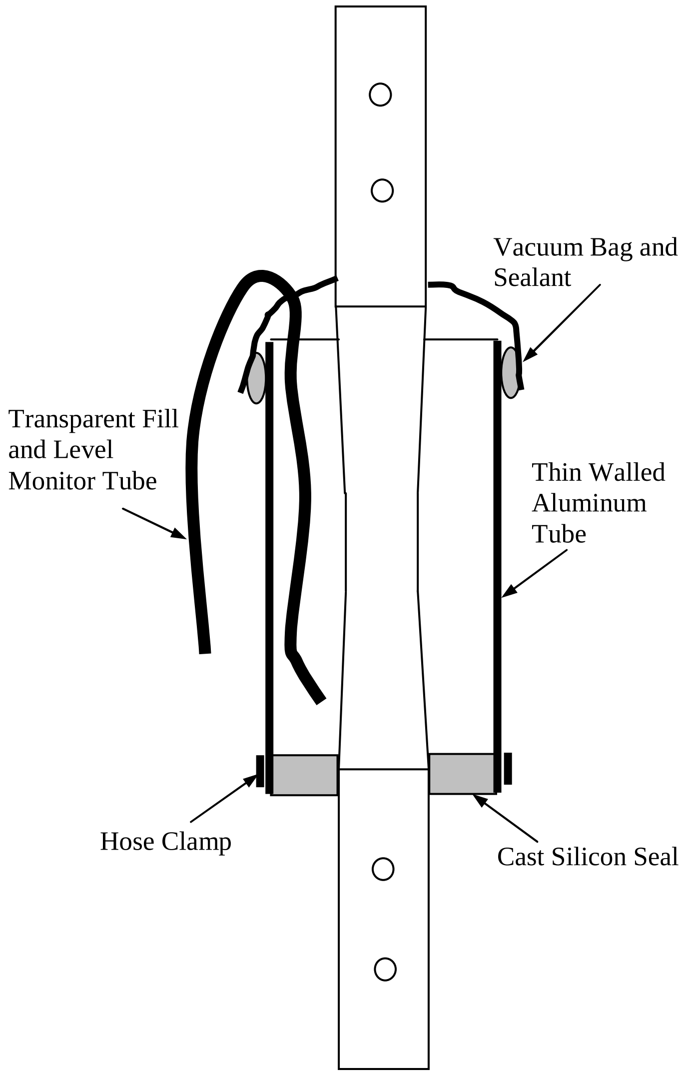

Figure 5. Caustic Liquid Containment

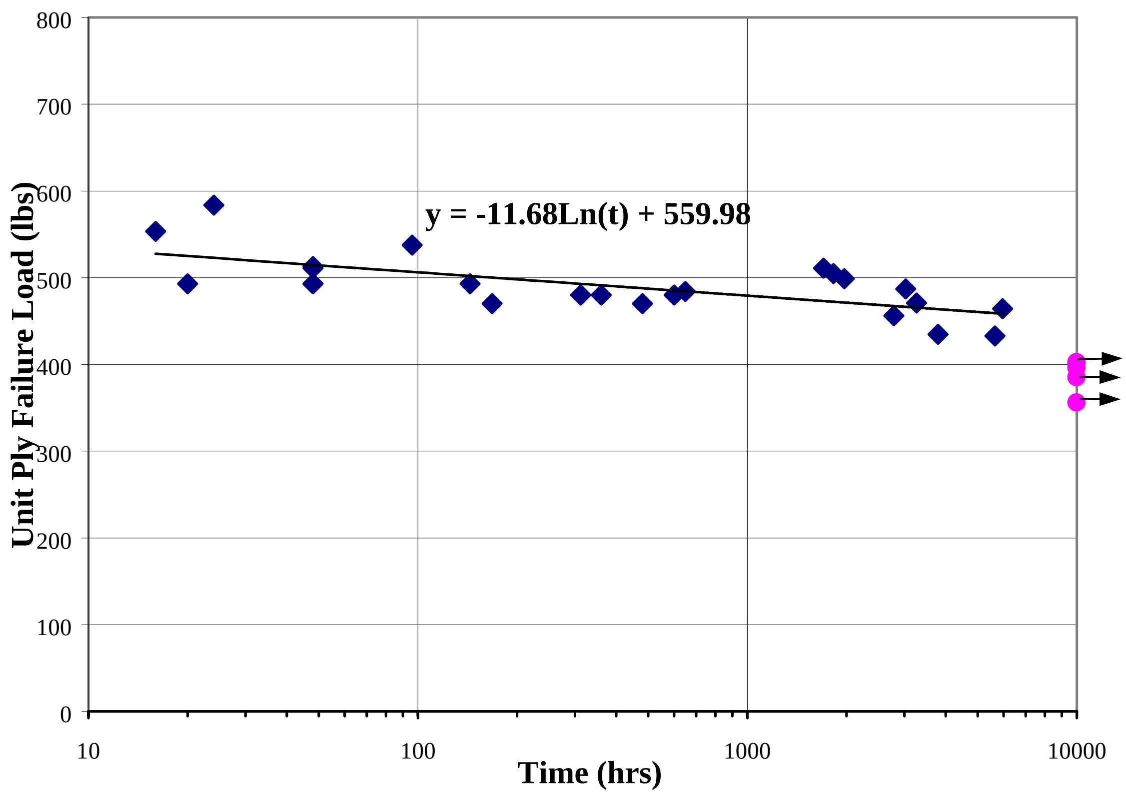

Figure 6. Tensile Creep-Rupture @ Room Temperature

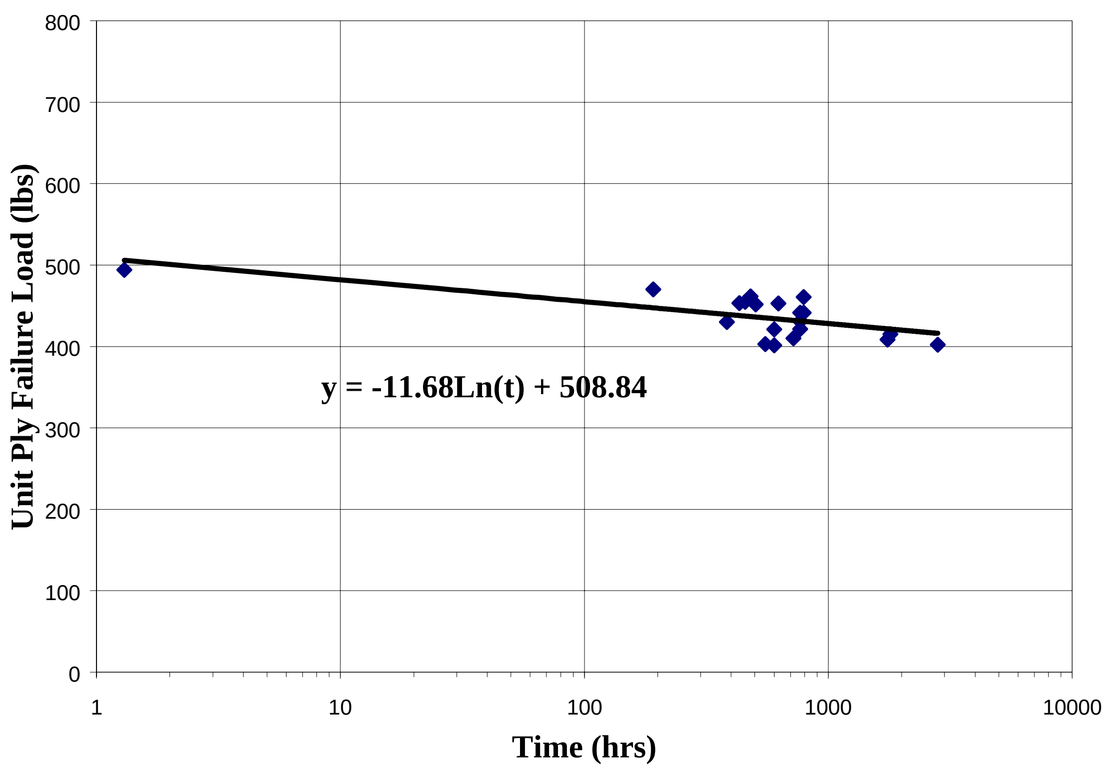

Figure 7. Tensile Creep-Rupture @ 160°F

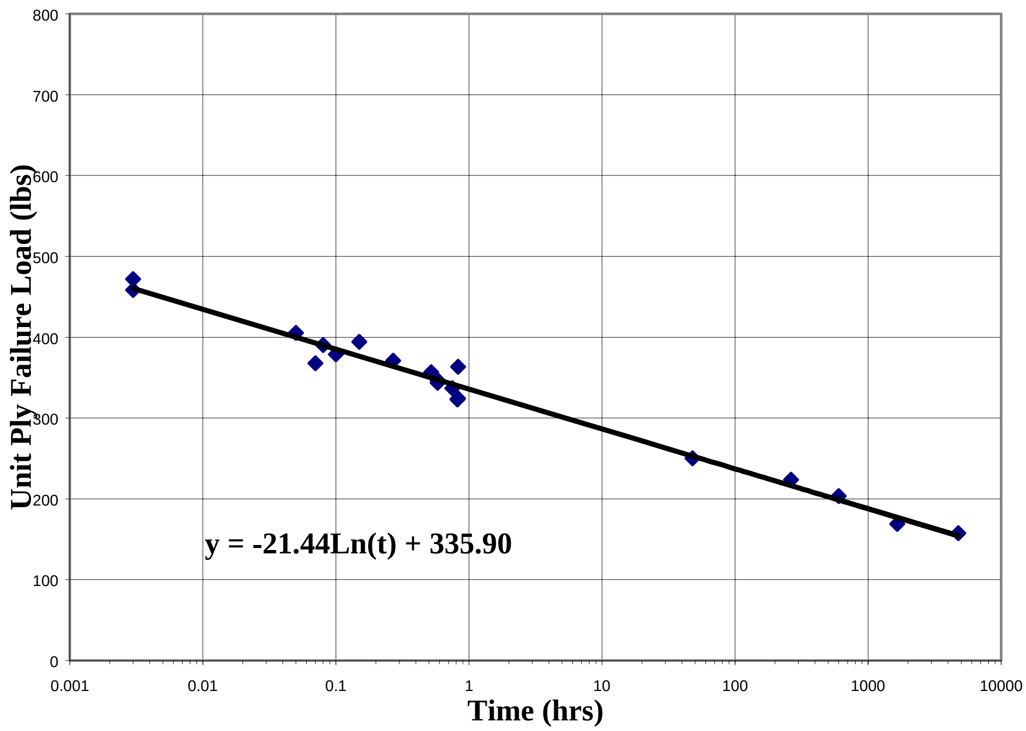

Figure 8. Tensile Creep-Rupture, 140°F Alkaline Soak