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Investigation of High Variability in the Creep Behavior of Vectran Yarn

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June 2021

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Space Administration

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Abstract

Inflatable structures are being pursued as candidates for long-term habitats in space and on the surfaces of the Moon and Mars. Many concepts by the National Aeronautics and Space Administration and industry utilize high-strength, low-weight softgoods materials, such as Vectran, as the primary load-bearing structure in inflatable habitats. Understanding the creep behavior of these materials at the yarn level, is a critical part of understanding the component and module level creep behavior that allows the design and safe use of these habitats for long duration missions. Initial creep tests performed on 20-lb rated Vectran yarn yielded a high degree of variability in the creep times to failure. In this paper, multiple facets of the test setup and approach are explored to identify possible sensitivities in performing creep tests on this type of synthetic yarn. Details of two different test methods to capture the creep-rupture behavior of Vectran yarn are documented. One method utilizes load amplification via lever-arms, while the other method utilizes a more conventional direct loading approach. In addition, two grip types are tested, and both high-speed videography and Scanning Electron Microscopy are used to observe the failure locations and yarn condition pre- and post-test. The characterization of the creep behavior with respect to the setup parameters indicate that the Vectran yarn tested in this project has an inherent high variability in creep failure times. Several additional parameters are identified for future investigation.

I. Introduction

The National Aeronautics and Space Administration (NASA) and industry are developing inflatable space structures to provide deployable habitable volumes for future exploration missions in space and on the surfaces of the Moon and Mars [1]. Inflatable structures are attractive due to their ability to be compactly stowed for launch and deployed to a much larger volume than the constraints of the launch fairing would typically allow. Due to the long-term nature of currently planned human exploration missions, crewed inflatable structures have many stringent requirements. One of the main structural requirements includes withstanding constant pressure loading over a multi-year mission which requires having resistance to creep failure modes in the constituent cordage and webbings that provide the primary structure of the vessel. The webbings and cordage are typically constructed using high-strength synthetic materials.

Creep is a time-dependent failure mode in which the specimen fails at a lower load than the ultimate strength, when loaded over an extended period of time. In addition to time, temperature may be a factor in creep failure. During creep testing, a specimen is loaded to a specified percentage of the ultimate load. Time to rupture (failure) is recorded and the elongation of the specimen is measured. Creep testing can be accelerated by testing the specimen at elevated temperatures, shortening the time to failure. Accelerated creep testing is beneficial for the time savings but adds a layer of complexity as the material properties must be well understood to confidently translate the accelerated data to real-time results. Creep test data are used to produce a master creep-curve of the material which plots creep strain versus time and is useful in design. Investigation of constituent yarn creep behavior is an important topic of research and is used to help understand the creep behavior at the component and module level [2]. The eventual goal of this area of research is to validate an accelerated creep test methodology for the softgoods components and modules. The study of constituent yarns is being performed to reduce the number of variables that may affect the creep behavior. The first step in this study is to obtain real-time creep data of the yarns that can be used in future comparisons to an accelerated creep test method.

The goal of the present study is to determine a test method to accurately measure the creep-rupture times of Vectran yarns. The test-stand design must have the ability to be fitted with an elongation measurement technique for use in future testing to determine the master creep-curves of the specimens. Additional requirements include the capability to test a large number of specimens concurrently so that many data points can be collected. Because the yarn specimens will fail at a lower load than webbings or cordage, the weights required and the physical footprint of the test stand will be smaller than that of a webbing or cordage test. The smaller weights and test footprint should allow for a higher number of creep tests to be performed on the yarn specimens as compared to a similar test set-up for a webbing or cord. The real-time creep data from the yarn can then be compared with future accelerated creep test data on yarn specimens. Potential correlation techniques can then be explored using the yarn data that can be used as the basis of an accelerated creep test approach for the components (webbings/cordage) and full-scale articles. Preliminary investigations of Vectran yarn have shown very high variability in creep rupture times. The current focus of this research is to eliminate potential variables in the test setup and test methods that may be contributing to the variability in the behavior.

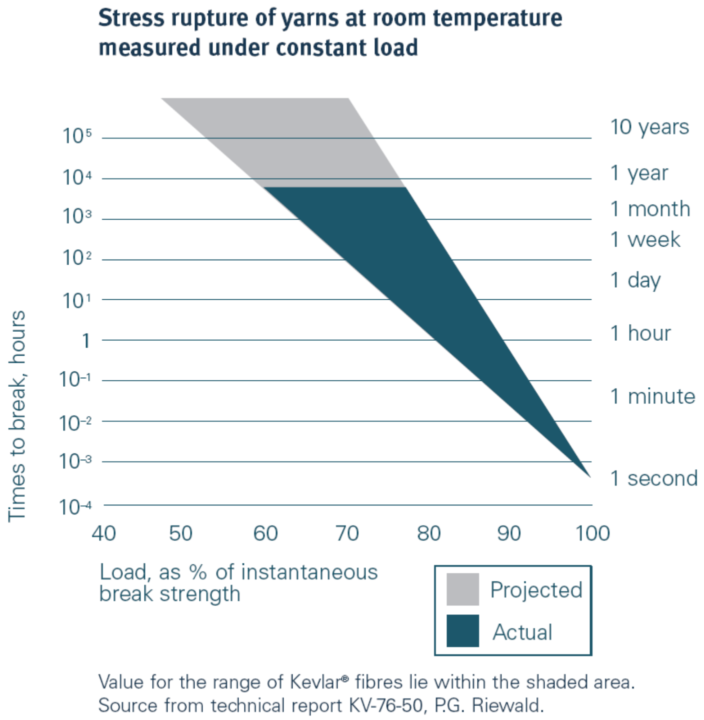
II.Vectran Yarn

The material tested for this creep study was Vectran yarn. Vectran is an aromatic polyester formed from a liquid crystal polymer (LCP). Vectran yarn was selected for this study as a follow-on to the study performed at NASA Langley Research Center (LaRC) where Vectran webbings were creep tested [3-5]. NASA Goddard Space Flight Center has also studied Vectran braided cords as a replacement for Kevlar cordage in static-loaded space flight applications [6]. As a material, Vectran has been proposed for use in inflatable space structures because Vectran has a high strength-to-weight ratio and the potential for improved creep performance. A magnified image of the Vectran yarn used in the creep testing is shown in Figure 1.

(a) (b)

Figure 1. Pictures of (a) pristine and (b) failed Vectran yarn taken via a USB microscope.

Vectran and other high-strength synthetic fibers, such as Kevlar, have been shown to have high variability in their creep behavior. The variability in webbing and cordage creep behavior for both Vectran and Kevlar can be seen in the results from Refs [3-6]. Yarns were theorized as potentially having less variability than webbings or cordage due to their fewer elements and more fundamental construction. However, this may not be the case as preliminary results for Vectran yarn have shown orders of magnitude variability in creep rupture time. The high variability has also been seen in Kevlar, as shown in Figure 2. As the figure indicates, at high percentages of loading (90% and above) the creep rupture times have a relatively small spread or scatter in failure times. However, very quickly as the percentage of load decreases, the creep rupture time can vary from hours to months at a set load point. The results shown in Figure 2 for Kevlar are similar to the preliminary results found for Vectran yarn during the present study.



Stress rupture of yarns at room temperature measured under constant load

Value for the range of Kevlar® fibres lie within the shaded area.
Source from technical report KV-76-50, P.G. Riewald.

Figure 2 Creep rupture times for Kevlar yarns. [7]

Two series of ultimate tensile strength (UTS) tests were performed on the spool of Vectran yarn used for the creep tests. Accurate determination of the UTS of the yarn was imperative because the load level used for the creep tests is set as a percentage of the average UTS. As described above, the creep rupture times are exponentially related to load level; a small variation in loading percentage can lead to a large change in creep rupture time. Two different grips were used during the different rounds of testing. Each set of grips were similar to the grips used in two different test stands, the conventional test stand which used roller grips, and the lever-arm test stand which used pulley grips. Both test stands are described in detail in Section III. The initial UTS test used standard yarn grips (which are similar to the grips in the conventional test stand) which produced a UTS of 23 lbf with a 1.6 lbf standard deviation. The second round of testing was performed using the pulley grips from the lever-arm test stand to determine if the grips had an effect on the behavior of the yarn. This resulted in a UTS of 24 lbf, with a standard deviation of 1 lbf. Because the average UTS from the second round of tests was within the standard deviation of the first round, the lever-arm grips were determined to not have a signficant detrimental effect on the average UTS. Both rounds of testing were performed to the specifications in ASTM-D2256 - "Standard Test Method for Tensile Properties of Yarns by the Single-Strand Method." [8]

Table 1. Round 1 UTS testing results, using standard yarn grips.

Specimen	Failure Load (lbs)
1	24.121
2	24.784
3	22.176
4	24.271
5	20.179
6	22.496
Average Failure Load (lbs)	23.005
Standard Deviation (lbs)	1.578

Table 2. Round 2 UTS testing results, using lever-arm test stand pulley grips.

Specimen	Failure Load (lbs)
1	23.386
2	22.491
3	25.495
4	24.665
5	23.973
Average Failure Load (lbs)	24.002
Standard Deviation (lbs)	1.033

III. Test Stands

Two different test stands were used to accomplish the creep testing: a load amplified lever-arm test stand and a conventional creep test set-up.

A. Lever-Arm Test Stand

A lever-arm test stand was designed and fabricated that utilizes a lever-arm to amplify the load on each yarn specimen. The test stand was designed to apply a 10:1 load ratio to the yarns, and five specimens can be tested simultaneously in each test stand. For example, using a 2-pound weight would result in a 20-pound applied load. The test stand is designed to load each specimen up to 20 pounds, using the 10:1 load ratio as shown in the previous example. The lever-arm test stand is depicted in Figure 3. Five identical lever-arm test stands were built, allowing for up to 25 specimens to be tested at one time.

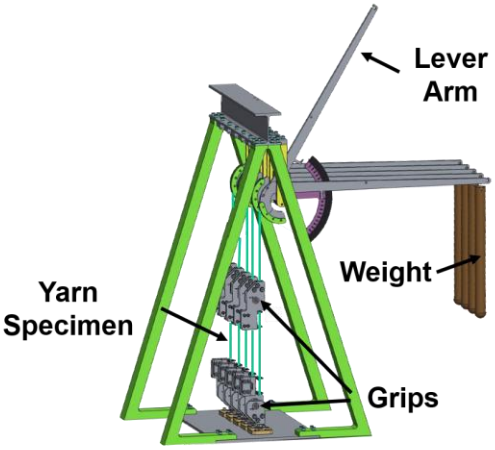
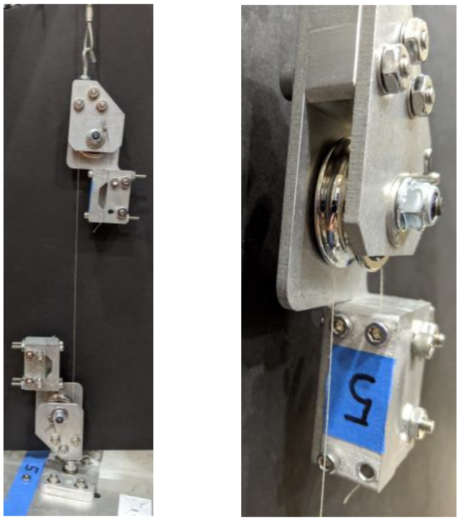


Figure 3. Annotated rendering of the lever-arm test stand.

The test stand has a footprint of 16 inches by 19 inches and stands 31 inches tall. Pulleys were used in the top and bottom grips (as shown in Figure 4), with the yarn wrapped around the pulley twice to reduce stress concentrations at the clamping point. The lateral spacing between the specimens is 2.5 inches. The specimen length in total is roughly 25 inches, leading to a test section length of 10 inches. The test section is defined as the tangent point on the wheel in each pulley.



(a) (b)

Figure 4. Lever-arm test stand: (a) top and bottom grips with yarn specimen, (b) close view of top grip.

To measure the creep rupture time of each specimen a camera was set up to take images at a set interval. Specifically, the set-up used a Raspberry Pi[1] camera in conjunction with a Python[1] script to automatically capture an image every 5 minutes. The time interval can easily be modified in the Python script to optimize for testing at different loading conditions. The timestamps on the images were used to determine when the specimens failed, giving the creep rupture time to the nearest 5-minute mark. Many different measurement systems were studied to measure the elongation of each specimen. Physical measurement devices, such as string pots, proved difficult to attach to the Vectran yarn specimen. Adhesives and mechanical fasteners often encountered slipping when the specimen was loaded due to the yarn specimen untwisting, and therefore the cross-section decreasing under load. If the mechanical fasteners were tightened to avoid slipping, a stress concentration was introduced leading to a premature failure at the fastening location. The current best solution for mechanical attachment that avoids slippage and does not seem to introduce a stress concentration is a 3-D printed solution. Two identical, roughly 0.5 inch square pieces, with an imprinted S- pattern on each half, create the fastener. Screws or clips can be used to hold the two sides together. The 3-D printed halves are shown in Figure 5. A string pot was initially used to measure the elongation of the yarn once a suitable fastening mechanism was found. However, the string pot was abandoned because the force to move the string was overcoming the force of the Vectran yarn elongating. Due to the difficulties of physical measurement of the specimens, optical measurement is now the baseline technique. A Keyence[1] Ultra-High Speed In-Line Profilometer laser is currently being set-up to measure the elongation of 2 of the 5 yarn specimens on a single test stand. The laser measures the distance between two markers on the yarn to determine the percent elongation. Currently small pieces of neoprene cord with a small slit cut in them are attached to the yarn as markers. The neoprene material is self-healing and very light, which allows the marker to stay on the yarn without slippage, without affecting the yarn's mechanical behavior.

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[1] The use of trademarks or names of manufacturers is for accurate reporting and does not constitute an official endorsement, either expressed or implied, of such products or manufacturers by NASA.

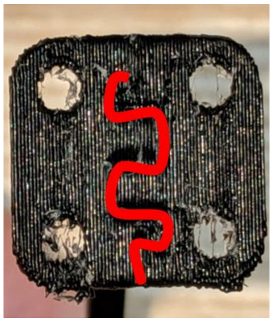

Figure 5. Image of a prototype 3D printed hardware attachment, with the indented snake pattern highlighted.

There are many benefits to using the lever-arm test stand. The use of load amplification via the lever-arms allows the use of smaller weights. The smaller weights are easier to procure and use while testing, resulting in a smaller test footprint. The smaller footprint allows for more specimens to be tested in a smaller area. However, the benefit of the small footprint can lead to testing difficulties. The small separation distance between specimens means one specimen may influence a nearby specimen’s behavior. The small footprint is also difficult to manually set-up, leading to potential for unknowingly imparting damage to the specimens during set-up. These concerns could be partially addressed by the addition of a load cell in the load path of the specimens, allowing for monitoring of the load throughout the entire test including setup. Better separation between specimens, or potential shielding, may also help reduce the chance for specimen interaction due to lateral movement. (Foam pieces, as shown in Figure 10, were used during testing to ensure separation.) Dampening or disconnecting the pivot points may also help reduce the possibility of vibrations being transferred. To address the concern of overloading the specimen during set-up, a through-pin or shelf could be added near the rear of the arm to prevent load being directly applied to the test specimen until the test is ready to begin.

B. Conventional Test Stand

Due to concerns that the lever-arm test stand may have been affecting the material behavior, a second test stand was designed. The conventional test stand was required to load specimens using no load amplification, a key differentiator from the lever-arm test stand. Other technical requirements included: using grips that would not alter the specimen behavior and would lead to specimen failure occurring in the test section and not in the grips, a set-up that could be used for loads from 5 lbs to 50 lbs, and a set-up process that was simple to replicate over many specimens. Additional requirements included the ability for the test stand to fit into a small area and use parts that were low-cost and easy to acquire or fabricate. The conventional test stand set-up utilized weights hanging from a rigid backstop. The labeled test set-up is shown in Figure 6.

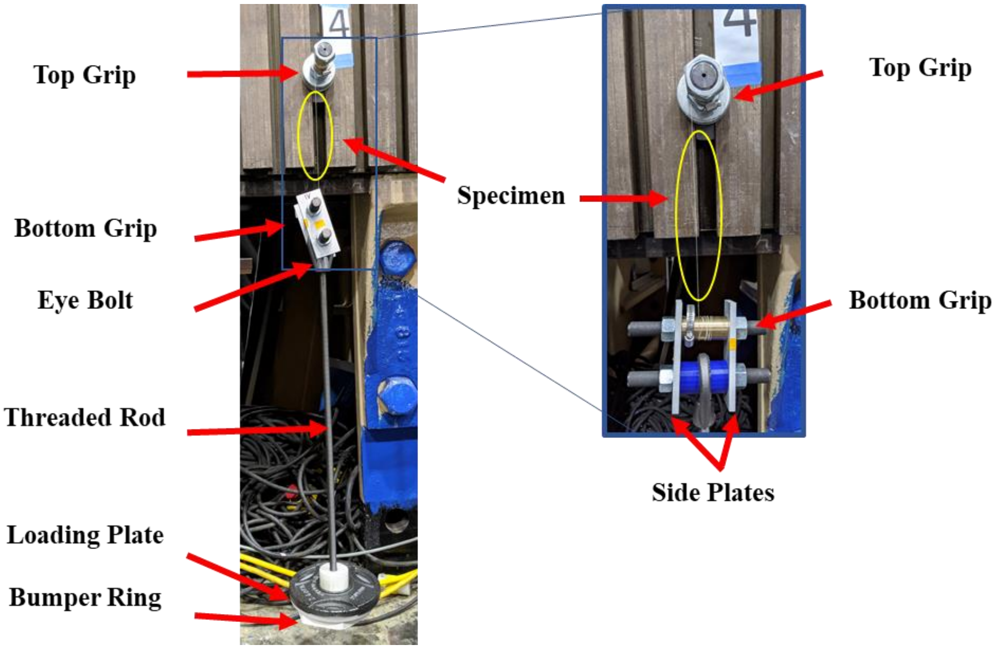

Figure 6. Conventional creep test stand hanging from rigid backstop.

The conventional test stand primarily consisted of commercial off-the-shelf parts. The loading plate located at the bottom of the threaded rod, and the two side plates for the bottom grip were fabricated using a water jet from spare aluminum at LaRC. Additional non-structural pieces, such as the bumper ring shown in Figure 6, were 3D printed out of extruded Polylactic Acid (PLA). Commercially available weights were used and each was measured via a calibrated scale before testing. This was not only a significant cost savings over purchasing calibrated weights, but also allowed for more precise loading conditions.

The top and bottom grips are shown in Figure 7. The basic premise for the grips was that the yarn would wrap around a 1-inch outer diameter bearing on both the top and bottom grips. The top grip consisted of a bolt used for the T-slotted rigid backstop and the bottom grip was constructed using two bolts placed through holes in the side plates (highlighted in Figure 6). The upper bolt had a 1-inch outer diameter bearing that the yarn was wrapped around, and the bottom bolt was used in conjunction with an eye bolt which is how the load was imparted on the specimen. The yarn was clamped around the bearing on both the top and bottom grip via a worm-drive clamp. The clamp can be seen in Figure 7.

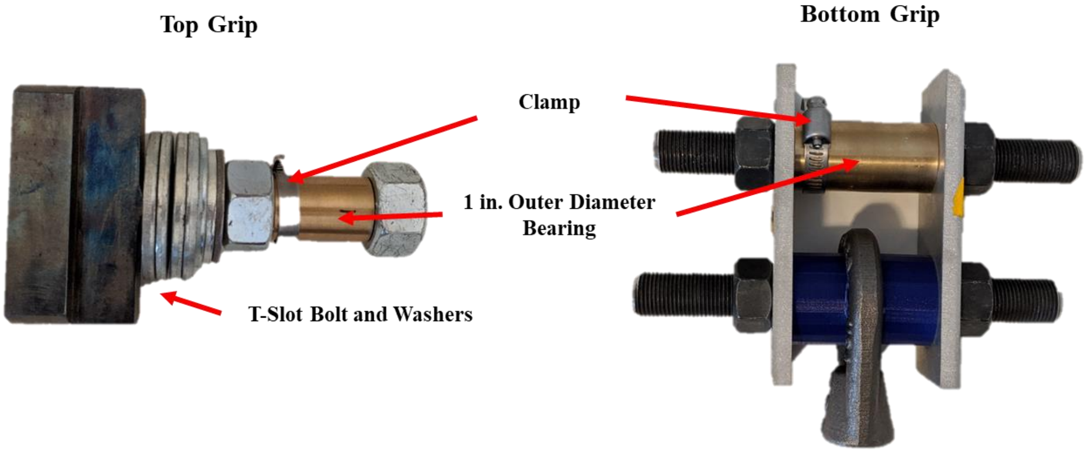

Figure 7. Top (left) and bottom (right) grips for the conventional test stand.

Pathfinder testing was used to determine that a specimen length of 61 inches wrapped 10 times around each grip would result in a 10-inch test section, or gage length, with failure occurring outside of the grip. The pathfinder testing was supplemented with high-speed cameras in order to verify that the specimens were not failing due to the grips. Failure occurring at, or between, the points of tangency on the grips is necessary for the test to be considered valid. The high-speed cameras were able to confirm that the yarn failure consistently occurred between the grip tangency points as needed. An example of an annotated image showing the failure initiation of a specimen below the tangency point of the top grip is shown in Figure 8.

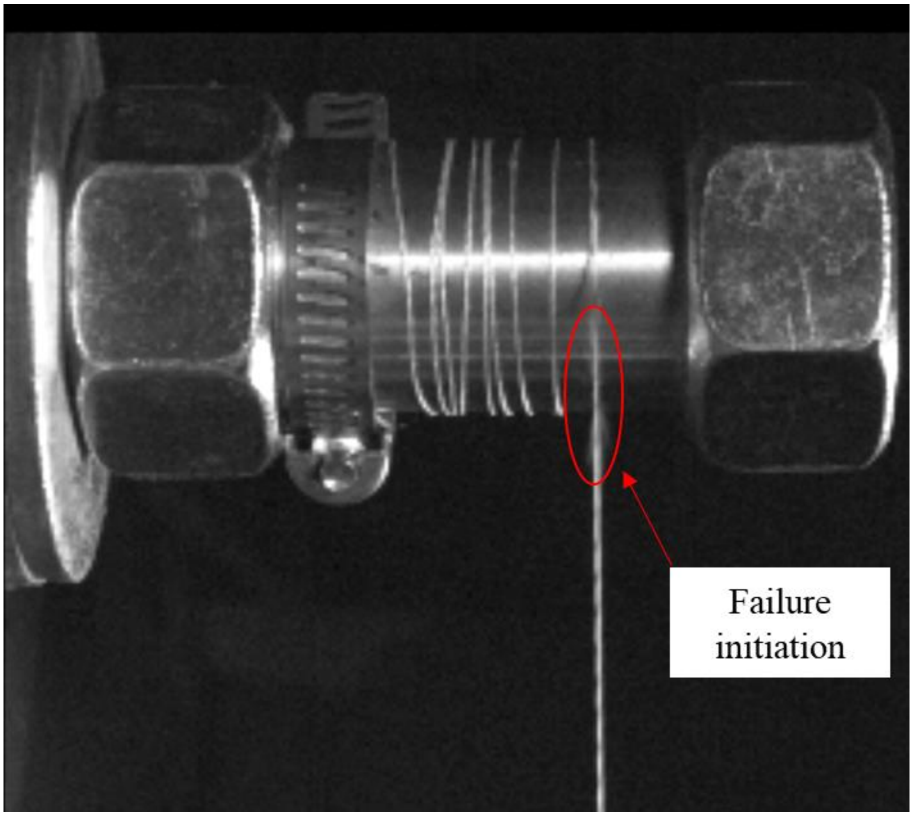

Figure 8. Frame taken from high-speed video capturing the failure initiation of a yarn specimen.

The final setup for the conventional test stand allowed for testing of five yarn specimens at one time. The final set-up is shown in Figure 9. The specimens were uniformly loaded by lowering a hydraulic pallet jack with the weighted ends of the specimens on a board clamped to the ends of the pallet jack. Similar to the lever-arm test stand, a camera was used to take pictures at set intervals to monitor the failure times of the specimens. The interval was determined by the chosen load level and expected time to failure. The large clock seen in Figure 9 was located within the frame of the pictures taken and used to determine the time of failure.

Figure 9. Conventional test stand final set-up, loading 5 specimens.

IV. Test Description

Both the lever-arm test stand and conventional test stand followed similar test methods. The basic steps to set-up and run both test stands is outlined below.

1. Prepare the test area by setting up the cameras and taking test pictures to determine proper camera placement and if any additional lighting is needed. Often supplementary lighting would be needed for overnight images if the main lights in the lab space were to be turned off.
2. Cut the Vectran yarn to the appropriate length for the test specimens.
3. Calculate and measure the necessary weights for the specified loading condition.
4. Secure the specimens into the grips, without applying any loading.
5. Take additional test images to confirm the image quality and confirm that lighting remains adequate. Confirm the automated image taking script is performing as desired.
6. Begin acquiring images.
7. Load the specimens and begin test.

V.Tests and Results

Testing was originally planned to be completed using only the lever-arm test stands, however a large variance in creep rupture times was observed when using these test stands. To help determine if something in the design of the lever arm test stand was affecting the yarn specimens, the simpler conventional creep test was setup and used for comparison. Testing the same material on two different test setups helped characterize if the large scatter in failure times was due to the test stand or the material itself.

A. Lever-Arm Test Stand

A single 70% UTS and multiple 85% UTS creep rupture tests were performed using the lever-arm test stand. The 70% UTS creep test is shown in Figure 10. In the figure, foam can be seen separating the lever-arms to prevent the weights from interacting with each other.

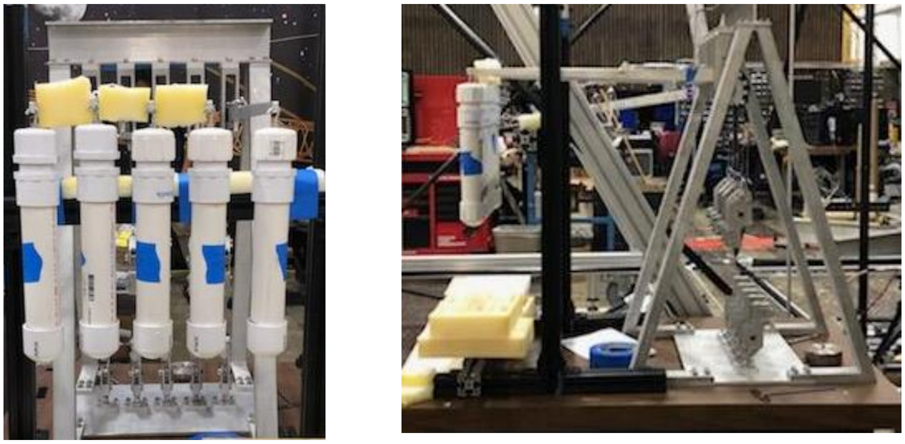

Figure 10. Front and side views of lever-arm test stand during 70% UTS load test.

The tests did not have a mechanism to measure the elongation, therefore only the time-to-failure, or creep-rupture time was measured. The time of failure of each specimen could then be found by reviewing the time stamp of the last image in which the yarn was still intact. The failure times, in hours, for the 70% UTS creep-rupture test are shown in Figure 11. The creep rupture times varied between 36 and 1162 hours, a difference of over six weeks. The high variance in failure times confirmed the findings of earlier preliminary tests and established that further study was required to determine if the lever-arm test stand or procedures were contributing to the variability or if the variability was inherent to the material.

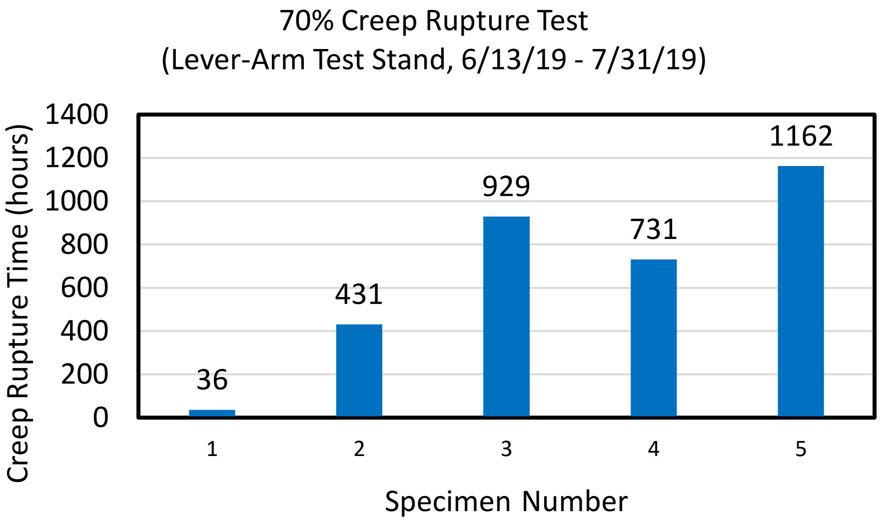

Figure 11. Creep rupture times, in hours, of a 70% UTS creep test on lever-arm test stand.

B. Conventional Test Stand

A 70% UTS creep-rupture tests were performed using the conventional test stand. The results are shown in Figure 12.

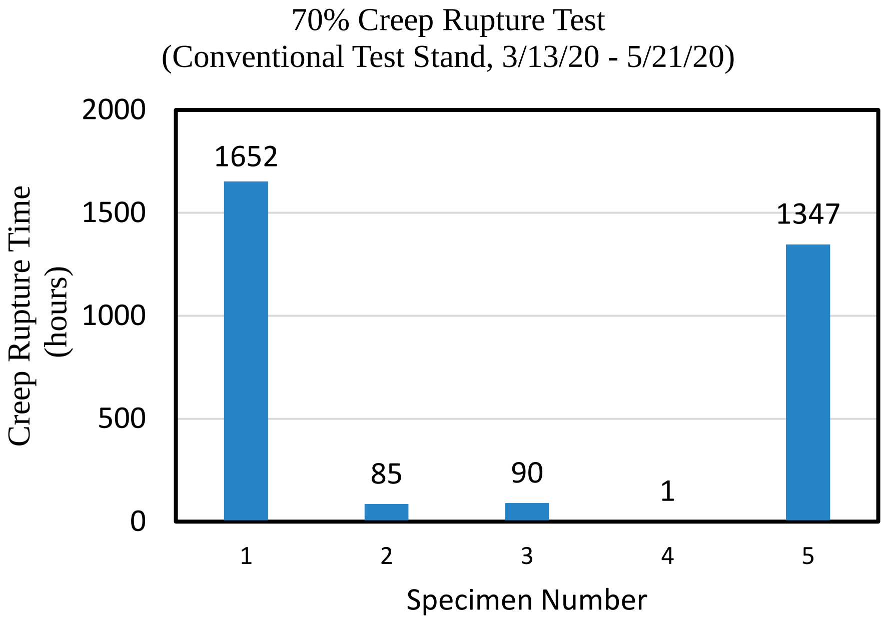

Figure 12. Creep rupture times, in hours, of a 70% UTS creep test on conventional set-up.

The failure times of the specimens shown in Figure 12 are in hours, the same time scale as the lever-arm test stand results. Specimen 1 may have lasted up to two weeks longer, but the system collecting photographs ran out of memory, the failure time shown is the last image captured. Similar to the lever-arm test, there was a large spread in failure times, ranging from 56 minutes to 10 weeks. The large spread in failure times was consistent with the lever-arm tests that were also run at 70% of UTS. The results from each test stand were consistent with variability seen in Kevlar yarns (see Figure 2), and therefore, pointed toward high variance in creep behavior being an inherent material characteristic for the Vectran yarn tested.

1. Scanning Electron Microscope (SEM) Images

Scanning Electron Microscope (SEM) images were taken of the failed specimens from the 70% UTS conventional test and pristine untested yarn. Due to the large spread of failure times in both test set-ups, the possibility that the behavior was inherent to the material was explored. One theory was that there may be differences of fiber diameters within each yarn, correlating to the differences in failure times. Therefore, measurements of the fiber diameter within the yarn were taken to determine if there was a correlation of fiber size to failure time. Both pristine yarn specimens, as well as specimens cut from the failed yarns from the 70% UTS conventional test were measured. An example of a pristine specimen and of a failed specimen are shown in Figure 13 and Figure 14, respectively.

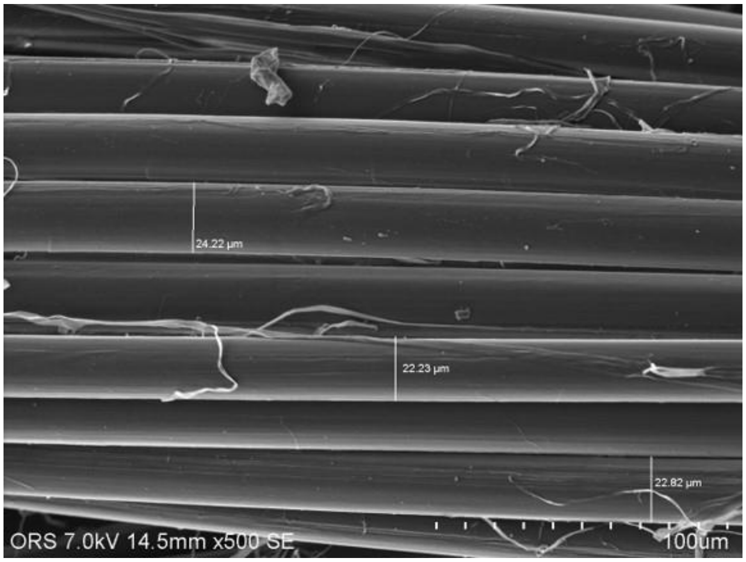

Figure 13. SEM image of a pristine yarn specimen.

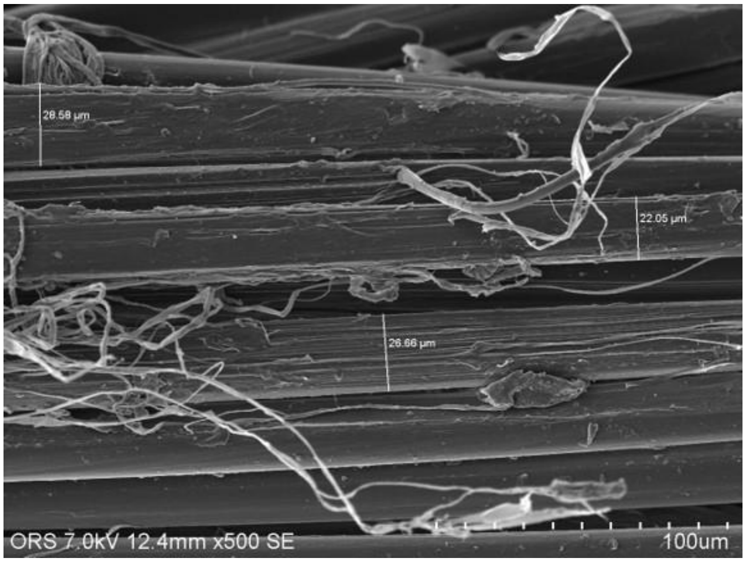

Figure 14. SEM image of a failed yarn specimen.

Ten specimens were sent for SEM analysis, three pristine, two each from the specimens with the longest and shortest failure times, and one each from all other specimens. The minimum, maximum, and average fiber diameter measurements were taken. The average was derived from ten separate measurements on each specimen. The results are summarized in Table 3.

Table 3. Fiber diameter measurements taken from SEM images.

Region	Min (µm)	Max (µm)	Average (µm)	Failure Time (hr)	Break Location	Legend
Pristine (1)	19.67	24.22	22.18	--	--	Pristine
Pristine (2)	20.1	24.02	22.25	--	--	Max/Min Specimen
Pristine (3)	20.95	24.35	22.82	--	--	Neither max/min
Test Stand 1 – Top	13.57	24.21	21.41	1652.2	Bottom	
Test Stand 1 – Bottom	18.27	23.14	21.74			
Test Stand 2 – Top	21.25	25.01	22.79	85.1	Middle	
Test Stand 3 – Top	20.49	24.76	22.12	91.1	Middle	
Test Stand 4 – Top	20.85	26.66	23.36	0.93	Top	
Test Stand 4 – Bottom	20.64	25.01	23.1			
Test Stand 5 – Middle	19.58	26.23	23.86	1347.2	Bottom	

No correlation was found in these SEM measurements between the average fiber diameter and the failure time. For example, the smallest average fiber diameter was the longest lasting specimen (Test Stand 1), but the second smallest average fiber diameter was from a specimen of middling failure time.

VI. Discussion of Results

The results of the creep-rupture tests from the lever-arm test stand show large differences in failure times, with the final specimen of the 70% UTS load test taking thirty-two times longer to fail than the first specimen. Multiple factors were considered as to why this large variation in failure times was observed. Setting up the test is a delicate process, and multiple people were used to set-up specimens, but no correlation between set-up person and failure time was found. The issue of "tolerance stack-up" was also considered. There was a possibility that the loading on each specimen location was not exactly a 10:1 ratio. Individual tests of certain specimen locations were performed using a load cell to confirm the loading ratio, but the results were inconclusive. The loading ratio was found to vary between test stands and specimen locations, with the less frequently used test stands having less measured variation between specimen locations. However, the results were not repeatable, and post-test, the calibration of the specific load cell used was called into question. The lack of repeatability and suspect calibration led to the decision to not present those results, but still led to a desire to actively track and record the load levels across all the specimens. Currently, a load cell is being integrated into the load train for each specimen location for future testing so that the loading ratio can be confirmed during the entirety of the test. If the loading was higher or lower than expected, this could account for the spread in failure times. Due to the relationship between time-to-failure and load level, a small change in load could lead to a large change in failure time. In addition to the difference in loading, variation in the UTS of the Vectran yarn from specimen to specimen could also lead to a different percentage of UTS loading than expected. These two variables combined could be leading to the large spread in failure times.

The results from the creep-rupture tests of the conventional creep test stand exhibited the same large spread in failure times that the lever-arm test stand did. These findings would point towards inherent variability in the Vectran yarn as the reason for the large spread in failure times, rather than an issue with the lever-arm test stand. One such theory, that the average fiber diameter may be related to the failure time of the specimen, was studied via SEM imaging. The specimens studied, however, did not indicate a correlation between average fiber diameter and creep rupture failure time. There may also be a telescoping phenomenon occurring, leading to a more progressive failure versus a sudden brittle failure. The yarns that experience the telescoping phenomenon may be lasting longer than the brittle failures. This type of behavior is seen in nanotubes [9] and can be studied via additional SEM imaging in the future. Additional study into the manufacturing technique of Vectran yarn has also led to the conclusion that the manufacturing process will lead to fairly uniform fiber diameters. However, additional material characteristics could still be affecting the creep behavior of the specimen, such as fiber twist and the amount of sizing applied. Further research into other properties of the yarn construction and constituent materials would be areas for continued research. Testing of additional high-strength synthetic yarns to see if similar variance occurs are also areas of future study.

In addition, more tests need to be performed on each test stand at different percentages of ultimate load, as well as repeat tests at the 70% UTS load. While preliminary testing at other load levels suggests the behavior is highly sensitive to the load level, that sensitivity has not yet been quantified.

VII. Concluding Remarks

This study researched multiple aspects of a creep test setup and approach that were identified as possible influence factors on the highly variable creep time to failure observed in Vectran yarn. Vectran is of special interest due to the material’s high strength-to-weight, low creep capability, and is currently being used in designs for inflatable space habitats. Due to the long-duration mission applications for these habitats, determination of the creep behavior of the materials used is critical. One of the goals of this study was to identify and reduce variability in the test approach to provide an accurate method to determine the real-time creep behavior of Vectran yarns. This testing is focusing first on creep-rupture time, with the secondary goal of measuring the elongation of the yarns for future use in determining the master creep-life curves.

Two different test stands were used to determine the creep-rupture time of Vectran yarn: a lever-arm test stand and a conventional creep test set-up. Results from both test stands exhibited a large spread in the creep rupture time, with both test stands producing similar behavior at the same loading conditions. These results point towards an inherent variability in the material’s creep behavior, rather than an issue with the test stands themselves. The yarn has shown a high sensitivity to loading conditions. Additional testing and the integration of a load cell into the lever-arm test stand should lead to a better understanding of that sensitivity. In addition to creep-rupture testing, future development and testing is planned on approaches to measuring elongation and strain in the yarns so that the full creep-response curves for Vectran yarn can be derived. Additional testing of different yarns is also planned to confirm that the test stands are not affecting the outcome of the results for a less variable material.

References

1. Valle, G.D., Litteken, D. and Jones, T.C., “Review of Habitable Softgoods Inflatable Design, Analysis, Testing, and Potential Space Applications,” *AIAA SciTech*, AIAA 2019-1018, San Diego, CA, 2019.

2. Giannopoulos, I.P., “Creep and Creep-Rupture Behavior of Aramid Fibers,” Ph.D. Dissertation, Dept. of Engineering, University of Cambridge, Cambridge, England, 2009.

3. Jones, T.C. and Doggett, W.R., “Time-Dependent Behavior of High-Strength Kevlar and Vectran Webbing,” *AIAA SciTech*, AIAA 2014-1328, National Harbor, MD, 2014.

4. Kenner, W.S., et al., “Long Term Displacement Data of Woven Fabric Webbings under Constant Load for Inflatable Structures,” *AIAA SciTech*, AIAA 2014-0352, National Harbor, MD, 2014.

5. Jones, T.C., et al., “Accelerated Creep Testing of High Strength Liquid Crystal Polymer Webbing,” *53rd AIAA Structural Dynamics and Materials Conference*, AIAA 2012-1771, Honolulu, HI, 2012.

6. Fette, R.B., and Sovinski, M.F., “Vectran Fiber Time-Dependent Behavior and Additional Static Loading Properties,” NASA-TM 2014-212773, Greenbelt, MD, 2004.

7. O'Riorden, S. and Mahapatra, A., "Comparison of Static and Dynamic Strength of Rugged Optical Cables," Linden Photonics. Accessed 6/11/2021. http://www.lindenphotonics.com/documents/Linden%20-%20Comparison%20of%20Static%20and%20Dynamic%20Strength%20of%20Rugged%20Optical%20Cables.pdf

8. ASTM Standard D2256, 2015, "Standard Test Method for Tensile Properties of Yarns by the Single-Strand Method," ASTM International, West Conshohocken, PA, 2015, www.astm.org.

9. Kim, J.W., et al., "Polyaniline/Carbon Nanotube Sheet Nanocomposites: Fabrication and Characterization," *ACS Applied Material & Interfaces*, Vol. 5, No. 17, 2013, pp. 8597-8606. https://doi.org/10.1021/am402077d

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14. ABSTRACT

Inflatable structures are being pursued as candidates for long-term habitats in space and on the surfaces of the Moon and Mars. Many concepts by the National Aeronautics and Space Administration and industry utilize high-strength, low-weight softgoods materials, such as Vectran, as the primary load-bearing structure in inflatable habitats. Understanding the creep behavior of these materials at the yarn level, is a critical part of understanding the component and module level creep behavior that allows the design and safe use of these habitats for long duration missions. Initial creep tests performed on 20lb rated Vectran yarn yielded a high degree of variability in the creep times to failure. In this paper, multiple facets of the t

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