Comparison Testing and Analysis of Braided Cords Constructed from Varying Kevlar Fiber Types

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Motivation

Parachute systems are critical and require detailed knowledge of all aspects of their design and construction to ensure success. The materials used to construct these systems have advanced over time.

- Kevlar (i.e., aramid) is commonly used in parachute applications due to its high strength to weight ratio. Kevlar was first introduced commercially in the 1970s, originally by DuPont, now Arclin, and now exists in multiple formulations.
- Kevlar cords for parachute applications are controlled via procurement specifications (e.g., Parachute Industry Association specifications, such as PIA-C-87129)
    - PIA-C-87129 covers, "braided aramid, intermediate modulus of elasticity coreless cord", but does not explicitly specify acceptable varieties of Kevlar fiber types which can be used, nor an explicit range of modulus values considered to be intermediate.
- **New formulations of Kevlar are likely to emerge, and existing formulations may become obsolete in the future.** Parachute engineers must understand how the material properties change due to a material upgrade and if there are expected impacts to overall performance of the parachute.
    - Potential system impacts due to material changes could include changes in element strength, elongation, stiffness, abrasion resistance, and packability.
    - Elongation and modulus data for varying yarns is readily available and supplied by aramid manufacturers, but these properties are not as well defined for constructed cords.
- **The objective of this test was to measure the elongation of different Kevlar types at both the cord-level and at the yarn-level to determine if a change in Kevlar type impacted parachute performance.**

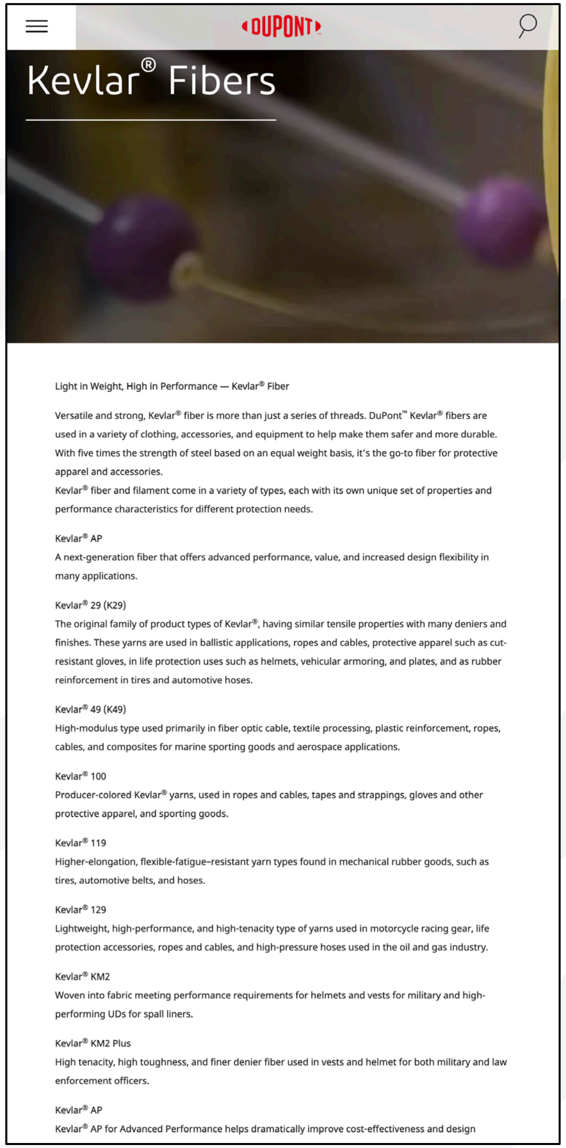
Kevlar Fiber Types Summary

DuPont, now Arclin, has many variations of the para-aramid Kevlar based on improved technologies as well as application-specific properties

- The “recipe”, which may include parameters like polymer alignment and spinning processes, can create fibers with different tenacity, modulus, and thermal or impact resistance
- Denier, filament count, and finishing treatments can further tune performance

Example primary Kevlar fiber types include

- Kevlar 29 – Standard high-strength fiber used in ballistic vests, ropes, and cables
- Kevlar 29AP – Enhanced version of 29 with better strength-to-weight and improved cost-efficiency
- Kevlar 129 – High-tenacity fiber optimized for advanced soft body armor and protective gear
- Kevlar KM2 – Designed for military applications, balancing toughness, and flexibility under impact
- Kevlar LT – Lightweight variant developed for advanced ballistic protection with reduced bulk
- Kevlar 49 – High-modulus fiber primarily used in structural composites, aerospace, and sporting goods


DUPONT

Kevlar® Fibers

Light in Weight, High in Performance — Kevlar® Fiber

Versatile and strong, Kevlar® fiber is more than just a series of threads. DuPont™ Kevlar® fibers are used in a variety of clothing, accessories, and equipment to help make them safer and more durable. With five times the strength of steel based on an equal weight basis, it’s the go-to fiber for protective apparel and accessories.
Kevlar® fiber and filament come in a variety of types, each with its own unique set of properties and performance characteristics for different protection needs.

Kevlar® AP
A next-generation fiber that offers advanced performance, value, and increased design flexibility in many applications.

Kevlar® 29 (K29)
The original family of product types of Kevlar®, having similar tensile properties with many deniers and finishes. These yarns are used in ballistic applications, ropes and cables, protective apparel such as cut-resistant gloves, in life protection uses such as helmets, vehicular armoring, and plates, and as rubber reinforcement in tires and automotive hoses.

Kevlar® 49 (K49)
High-modulus type used primarily in fiber optic cable, textile processing, plastic reinforcement, ropes, cables, and composites for marine sporting goods and aerospace applications.

Kevlar® 100
Producer-colored Kevlar® yarns, used in ropes and cables, tapes and strappings, gloves and other protective apparel, and sporting goods.

Kevlar® 119
Higher-elongation, flexible-fatigue–resistant yarn types found in mechanical rubber goods, such as tires, automotive belts, and hoses.

Kevlar® 129
Lightweight, high-performance, and high-tenacity type of yarns used in motorcycle racing gear, life protection accessories, ropes and cables, and high-pressure hoses used in the oil and gas industry.

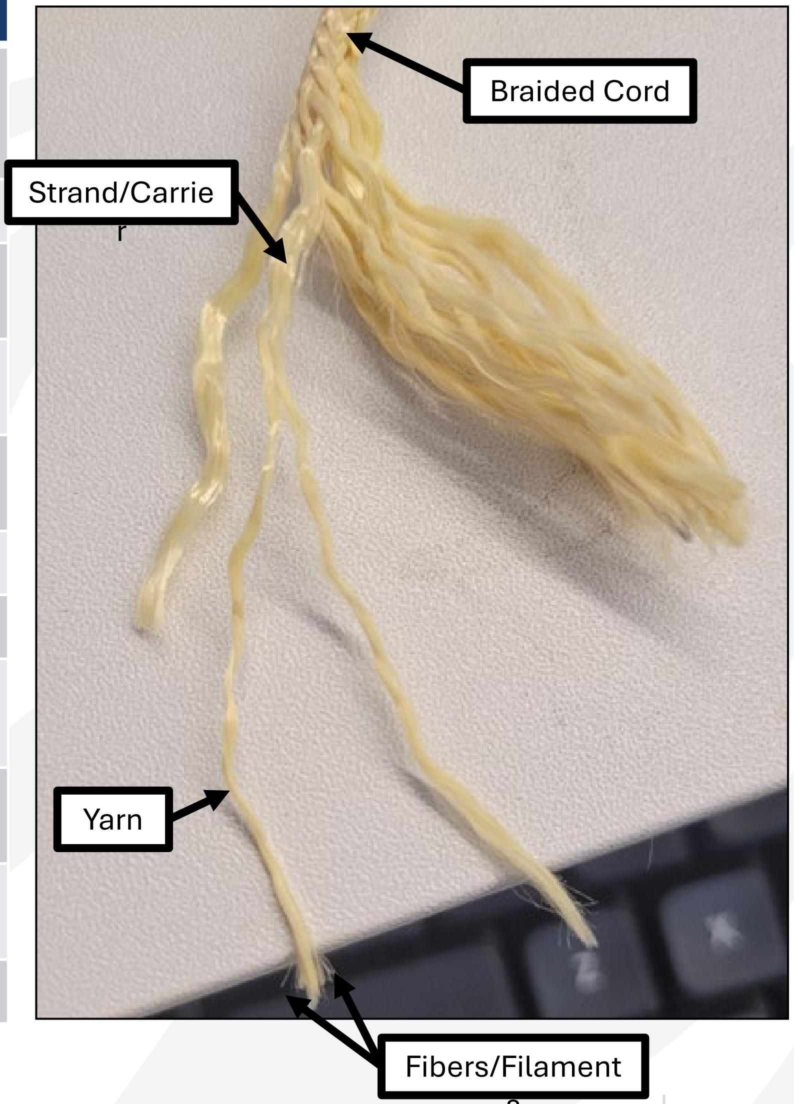
Kevlar® KM2
Woven into fabric meeting performance requirements for helmets and vests for military and high-performing UDs for spall liners.

Kevlar® KM2 Plus
High tenacity, high toughness, and finer denier fiber used in vests and helmet for both military and law enforcement officers.

Kevlar® AP
Kevlar® AP for Advanced Performance helps dramatically improve cost-effectiveness and design

Cord and Webbing Construction Background

Important Definitions	
Fiber	A unit of matter, natural or manufactured, that forms the basic element of fabrics and other textile structures. Kevlar fibers can come from Arclin in a variety of types (e.g., Kevlar 29, Kevlar 129, Kevlar KM2 Plus), each with a unique set of properties.
Filament	A fiber of an indefinite or extreme length.
Yarn	A generic term for a continuous strand of textile fibers, filaments, or material in a form suitable for weaving, braiding, or otherwise intertwining to form a textile fabric.
Strand	The largest individual element used in the final rope making process and obtained by joining and twisting together several yarns or groups of yarns.
Carrier	That part of a braiding/plaiting machine that holds the wound package of yarn, thread, cord, strand/multiple strand and carries this component when the machine is operated.
Cordage	A collective term for twines, cords, and rope made from textile fibers and yarns.
Cord	A small laid, plaited, or braided item of cordage, usually between 5/32" and 3/8" diameter (4mm and 10mm).
Webbing/ tape	A strong, narrow fabric, closely woven in a variety of weaves and principally used for belts and straps that can withstand strain, typically as a flat strip.
Denier	The weight, in grams, of 9000 meters of fiber/yarn. The lower the denier number, the finer the size of fiber/yarn. The higher the number the larger the size of fiber/yarn.
Merge	A group to which fiber production is assigned based on properties and dye-ability. All fibers within a merge can be expected to behave uniformly, and for this reason, can be mixed or used interchangeably.
Modulus	Slope of linear portion of stress/strain curve.



Kevlar Testing Overview

Primary Objective: Measure load and displacement time histories for various Kevlar cord and yarn samples in a cyclic load profile

- Modulus of Elasticity = $\frac{\sigma(\varepsilon)}{\varepsilon} = \frac{F/A}{\Delta L/L_0}$
- Measurements:
  - L_0, initial length (use length at ~20 lbf hand tension)
  - F(t), force over time
  - ΔL(t), crosshead displacement over time
  - Less concerned about cross-sectional area, A, since we are comparing between like samples.

Materials:

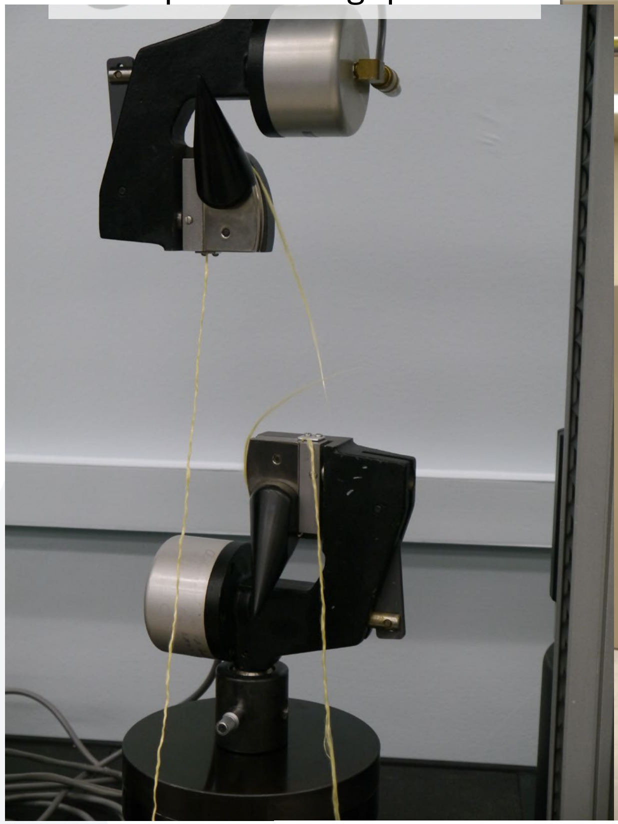
- Kevlar 29AP: 2000 lbf cord and yarn, 500 lbf cord and yarn
- Kevlar 129: 2000 lbf cord and yarn, 500 lbf cord and yarn

Approx 48 samples total: 24 cord samples and 24 yarn samples (see Test Matrix slide)

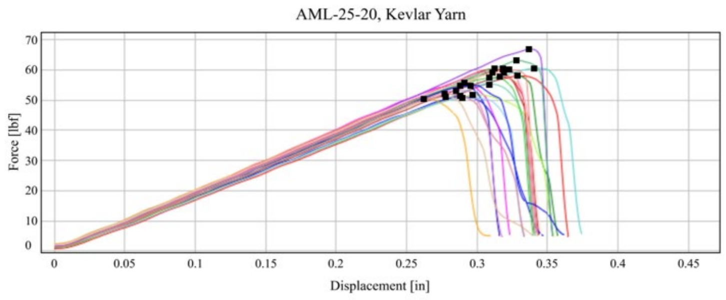
- Use Instron for cord samples with pin-to-pin connection
- Use Instron machine with pneumatic grips for yarn samples
- Cord samples will be roughly 2 yds long each (12 in center section + 18 in insertion x2 + 6 in eyelet loops x2 = 60 in)
- Roughly same length needed for yarn samples, but can use several yarns from a single cord

Each sample will be cycled 5x to the relevant max load (100% break strength or 30% break strength)

Thread Machine with pneumatic grips



Instron Machine with pin-to-pin connection

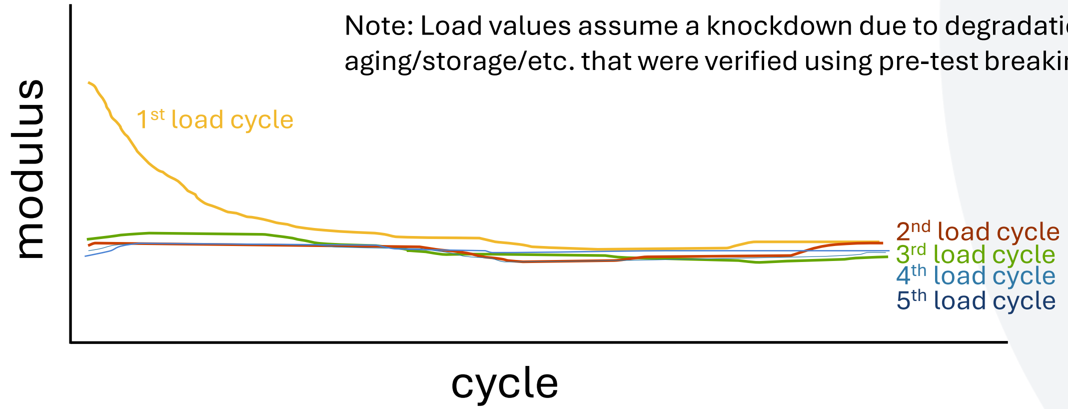


Test Matrix

- 48 samples total: 24 cord samples and 24 yarn samples
- Each sample underwent 1 load profile, which consists of 5 cycles to the relevant load (either 100% break strength or 30% break strength)

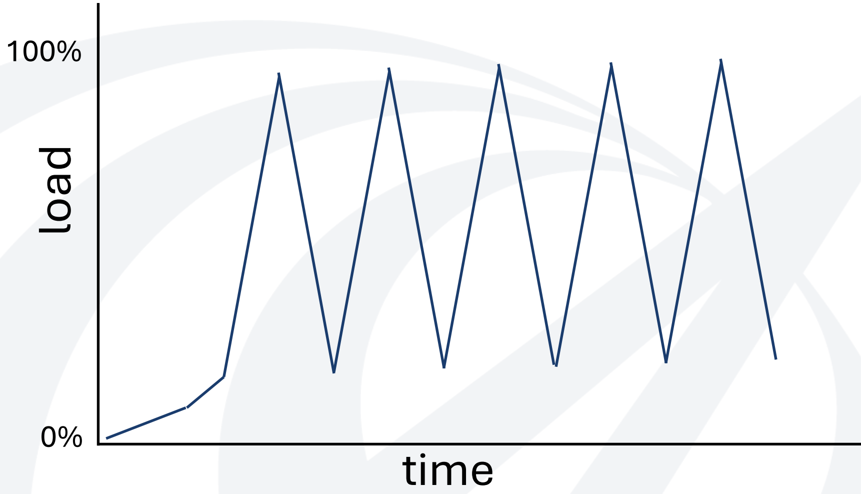
Note: 100% break strength (use Spec Strength) and 30% break strength (relevant as Peak Predicted Load)

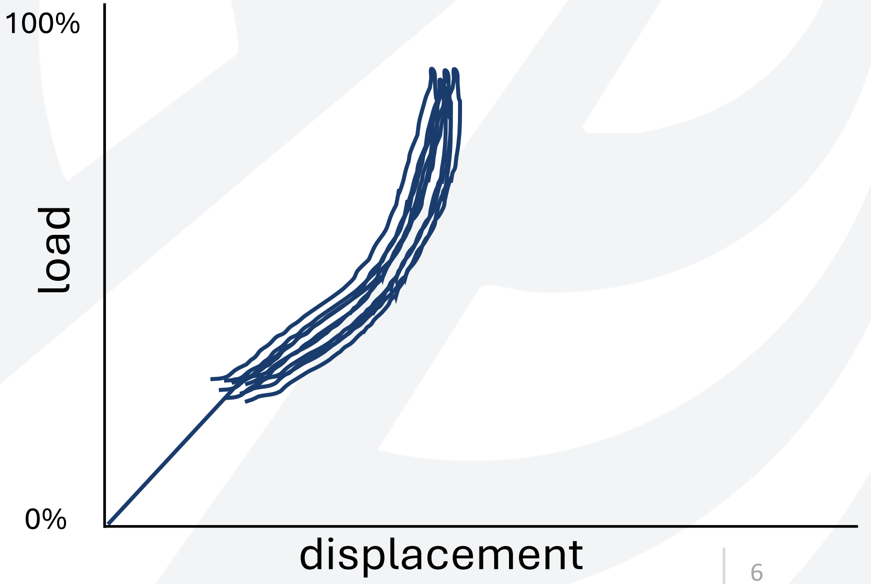
Type of Sample	Number of Samples	Kevlar 29AP 2000 lbf Cord	Kevlar 129 2000 lbf Cord	Kevlar 29AP 500 lbf Cord	Kevlar 29 500 lbf Cord
Cord	3	5x cycles to 100% cord break strength (1650 lbf)		5x cycles to 100% cord break strength (500-545 lbf)	
	3	5x cycles to 30% cord break strength (602 lbf)		5x cycles to 30% cord break strength (182 lbf)	
Yarn	3	5x cycles to 100% yarn break strength (38-40 lbf)		5x cycles to 100% yarn break strength (21-25 lbf)	
	3	5x cycles to 30% yarn break strength (16-17 lbf)		5x cycles to 30% yarn break strength (9-11 lbf)	

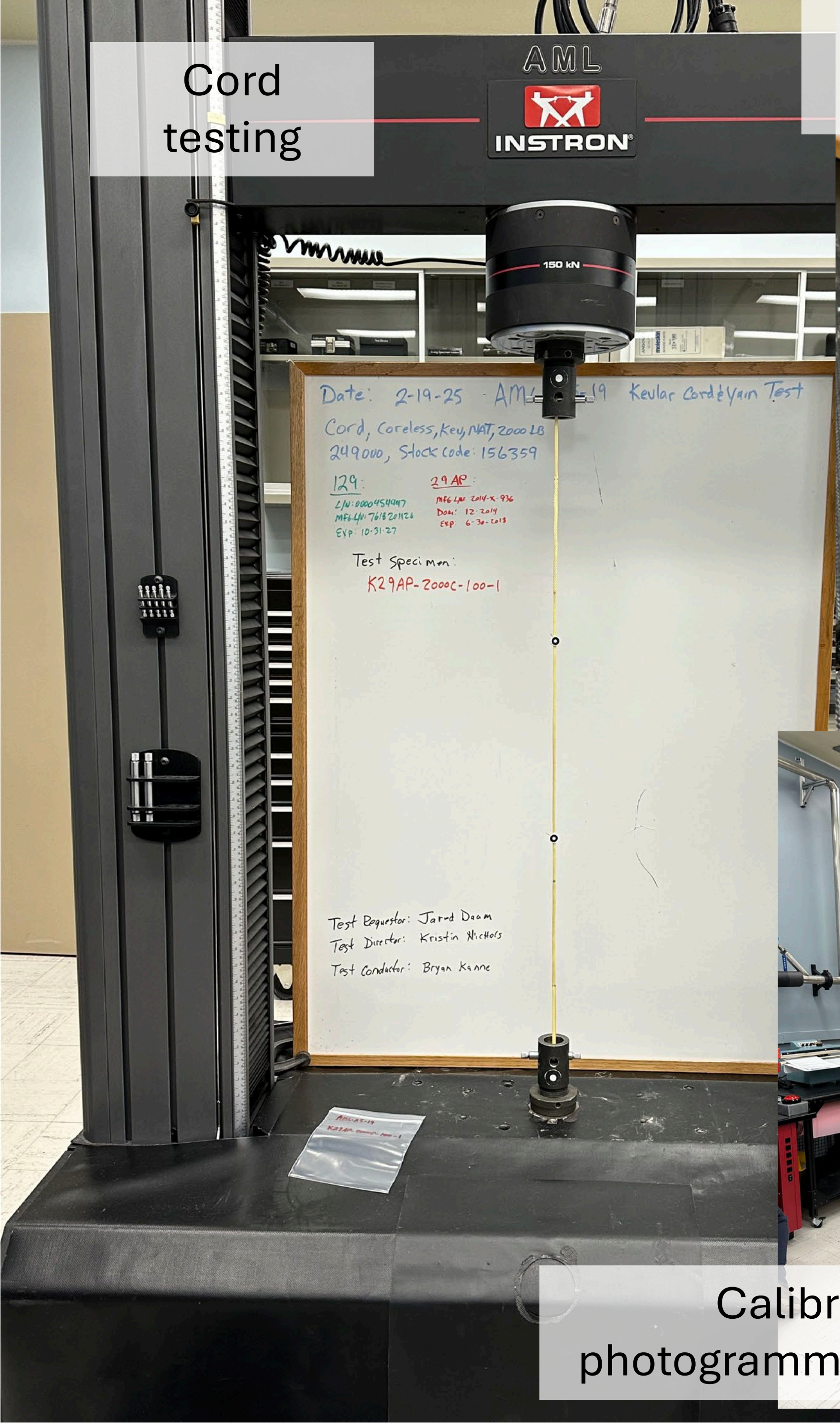


Note: Load values assume a knockdown due to degradation from aging/storage/etc. that were verified using pre-test breaking strength data.

1 Load Profile

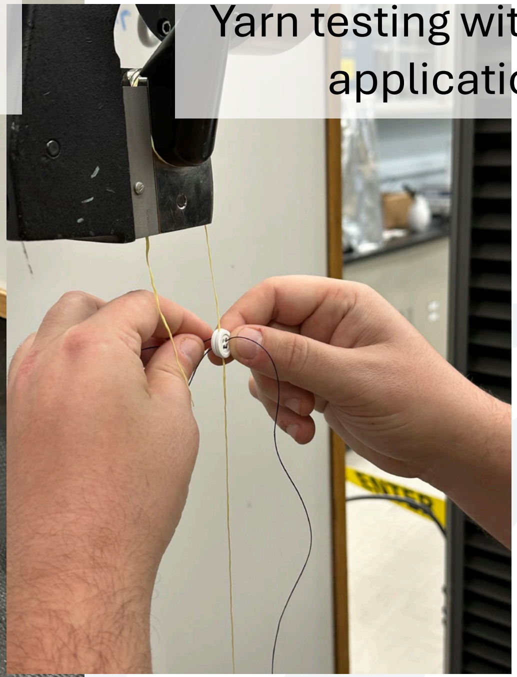


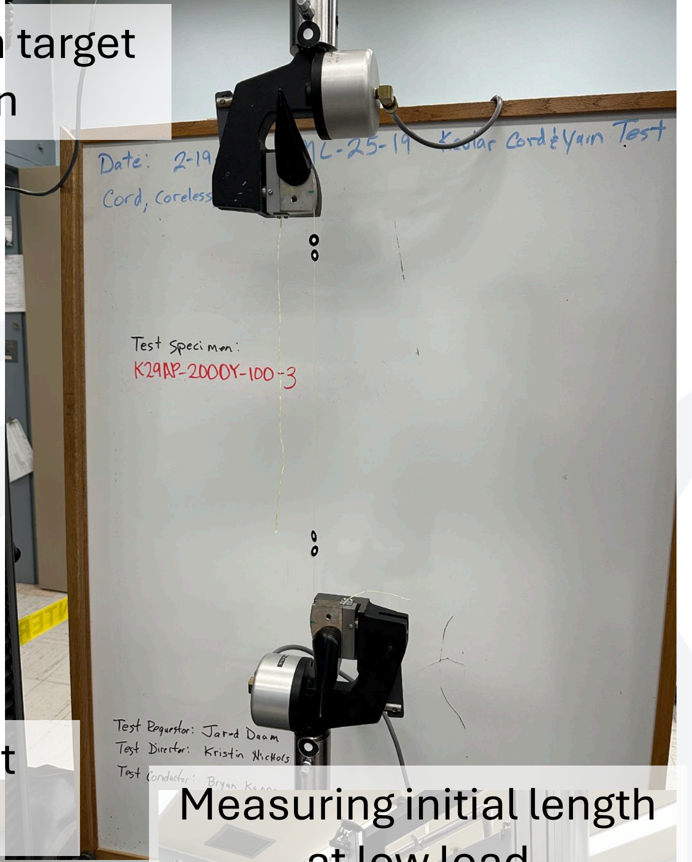




Cord testing


Insertion loop around pin connection


Yarn testing with target application




Calibrating photogrammetry system


Kevlar Modulus Test Team

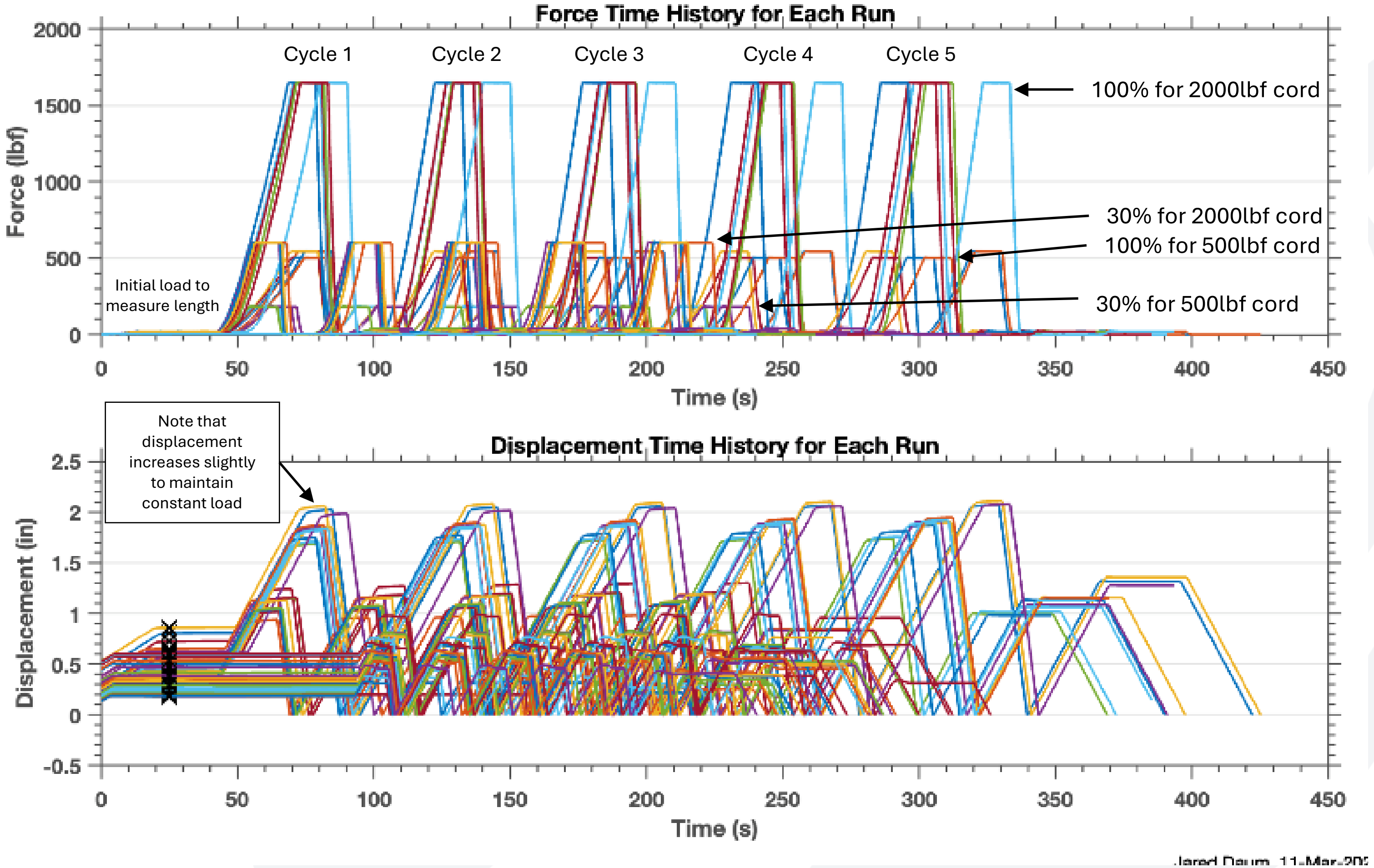

Measuring initial length at low load

Cord Force and Displacement Time Histories

Loading Profile:

- 1 in/min up to 20 lbf
- Pause to measure initial length
- Cycle x5
  - 3 in/min up to target load
  - Hold target load for 10 s
  - 12 in/min down to zero load
- 1 in/min up to 20 lbf
- Pause to measure length again

Note: Instron machine set to maintain constant load.



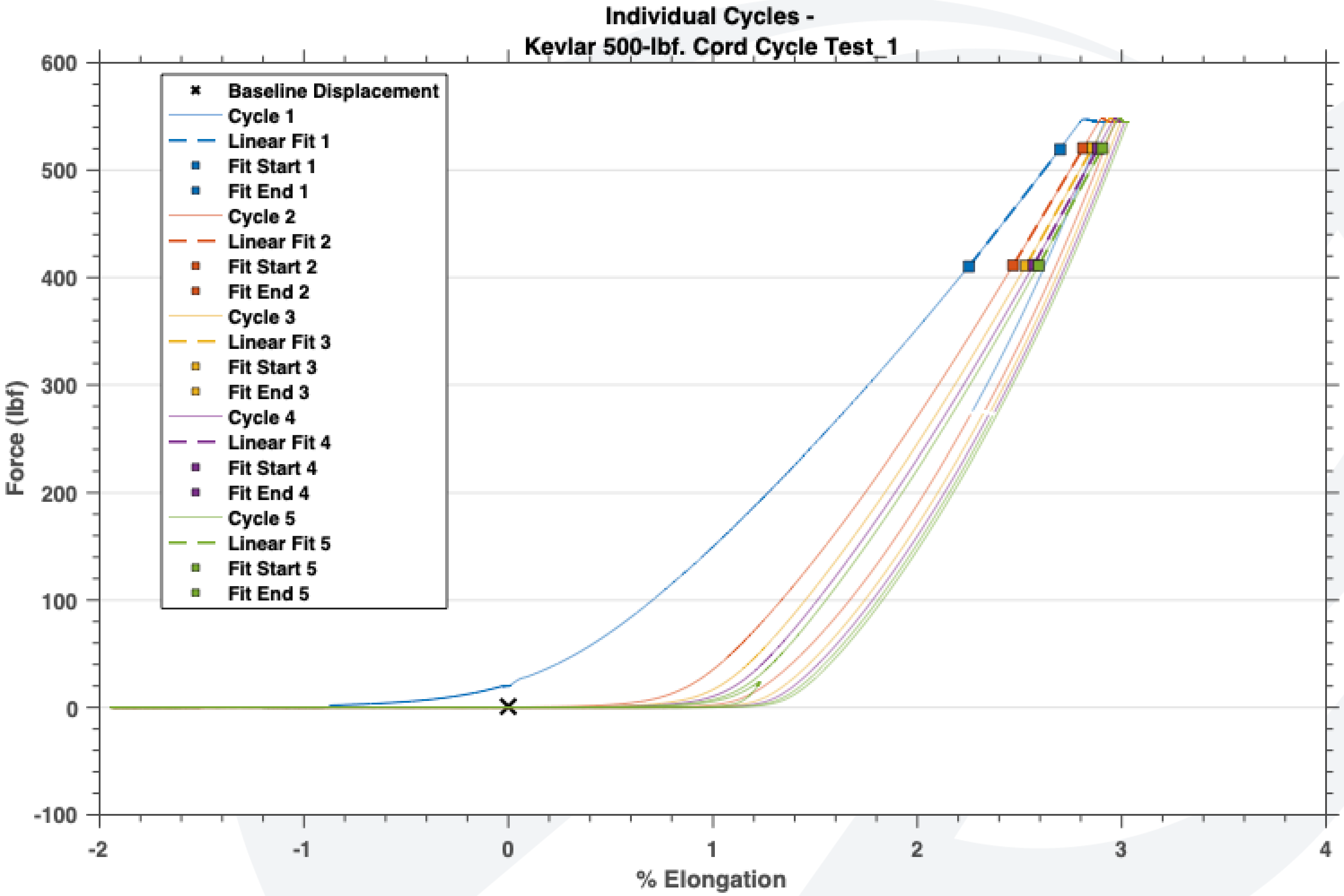
Example Kevlar Cord (500 lbf) Cycle Test

% Elongation = $\frac{\Delta L}{L_0}$

- ΔL calculated using the baseline crosshead (black X)
- L_0 measured at the initial 20 lbf load

Linear slope changes across the cycles

- Biggest difference seen between Cycle 1 and 2
- Slope settles out by Cycle 5
- Used 75% to 95% of target load used to calculate the linear slope



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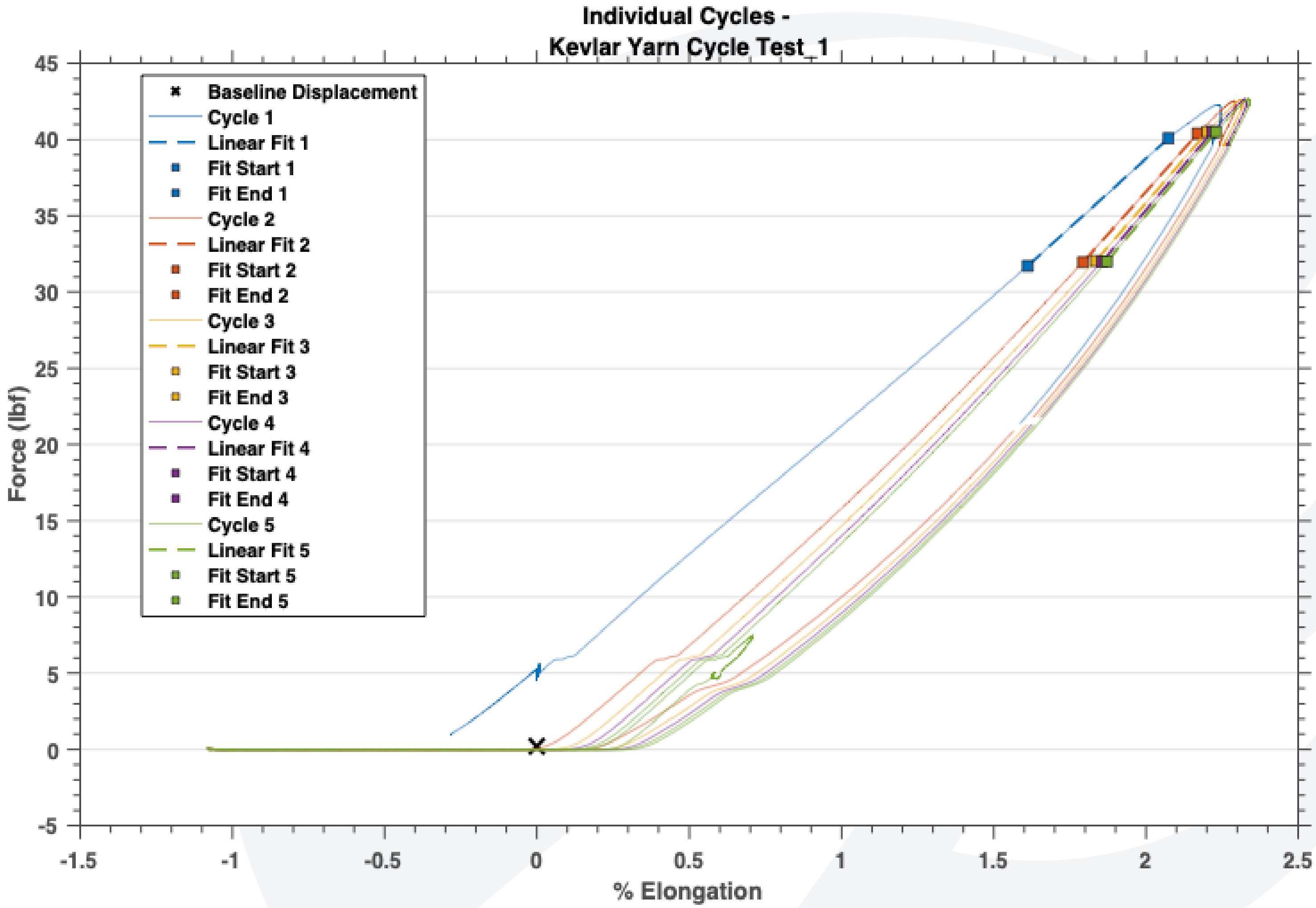
Example Kevlar Yarn Cycle Test

Similar results for the yarn samples

Linear slope changes across the cycles

- Biggest difference seen between Cycle 1 and 2
- Slope settles out by Cycle 5
- Used 75% to 95% of target load used to calculate the linear slope



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Cord: Mean Stiffness Per Family Across Cycles

Mean Stiffness = $\frac{\Delta F}{\Delta(\%\ Elongation)}$

For 2000 lbf cord:

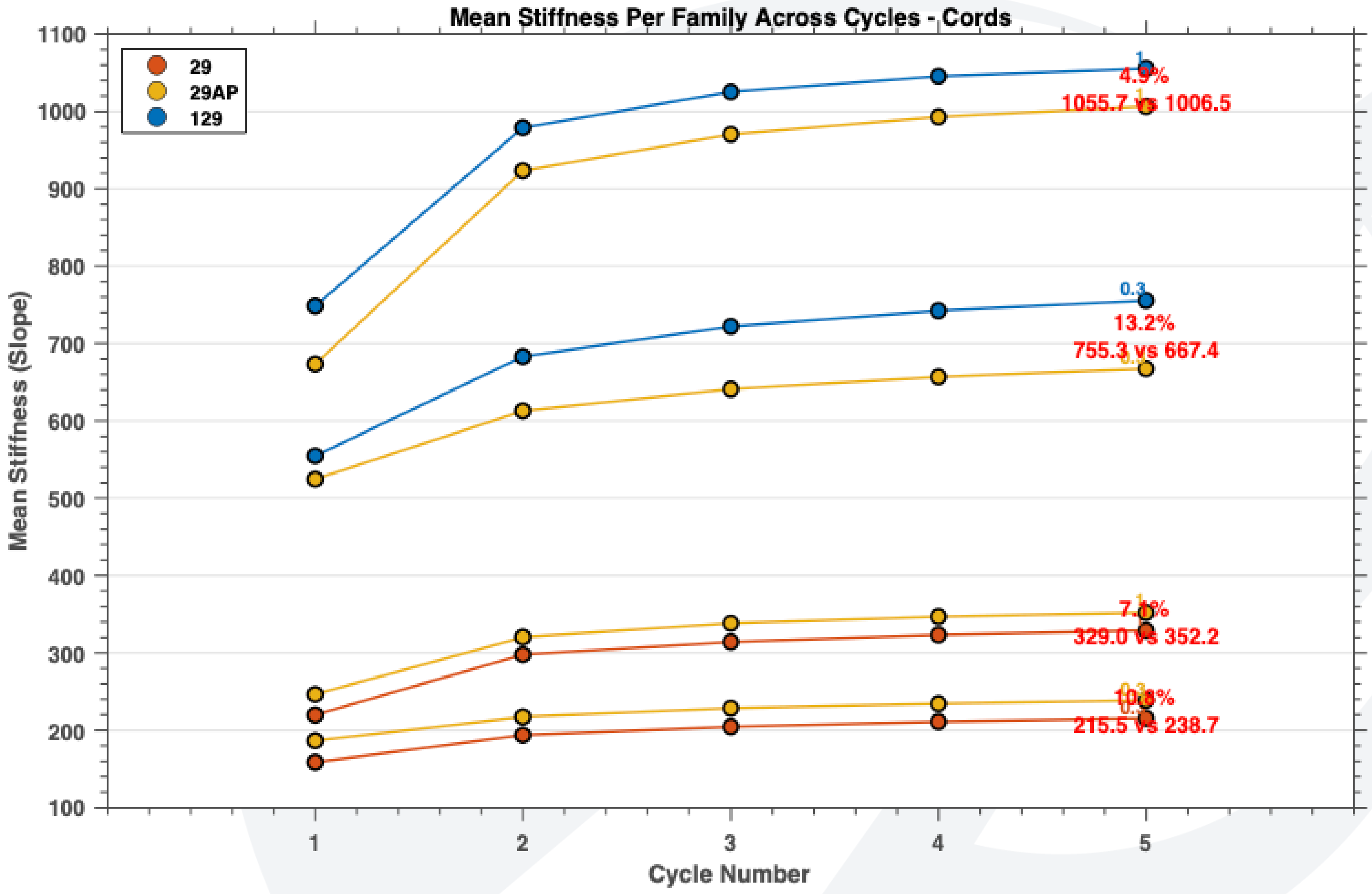
- Kevlar 129 is stiffer than Kevlar 29AP
- 4.9% stiffer at 100% load
- 13.2% stiffer at 30% load

For 500 lbf cord:

- Kevlar 29AP is stiffer than Kevlar 29
- 7.1% stiffer at 100% load
- 10.8% stiffer at 30% load

Stiffness of Kevlar:

- Kevlar 129 > Kevlar 29AP > Kevlar 29
- This aligns with the DuPont yarn-level modulus data



Yarn: Mean Stiffness Per Family Across Cycles

$$\text{Mean Stiffness} = \frac{\Delta F}{\Delta(\%\ Elongation)}$$

For 2000 lbf cord:

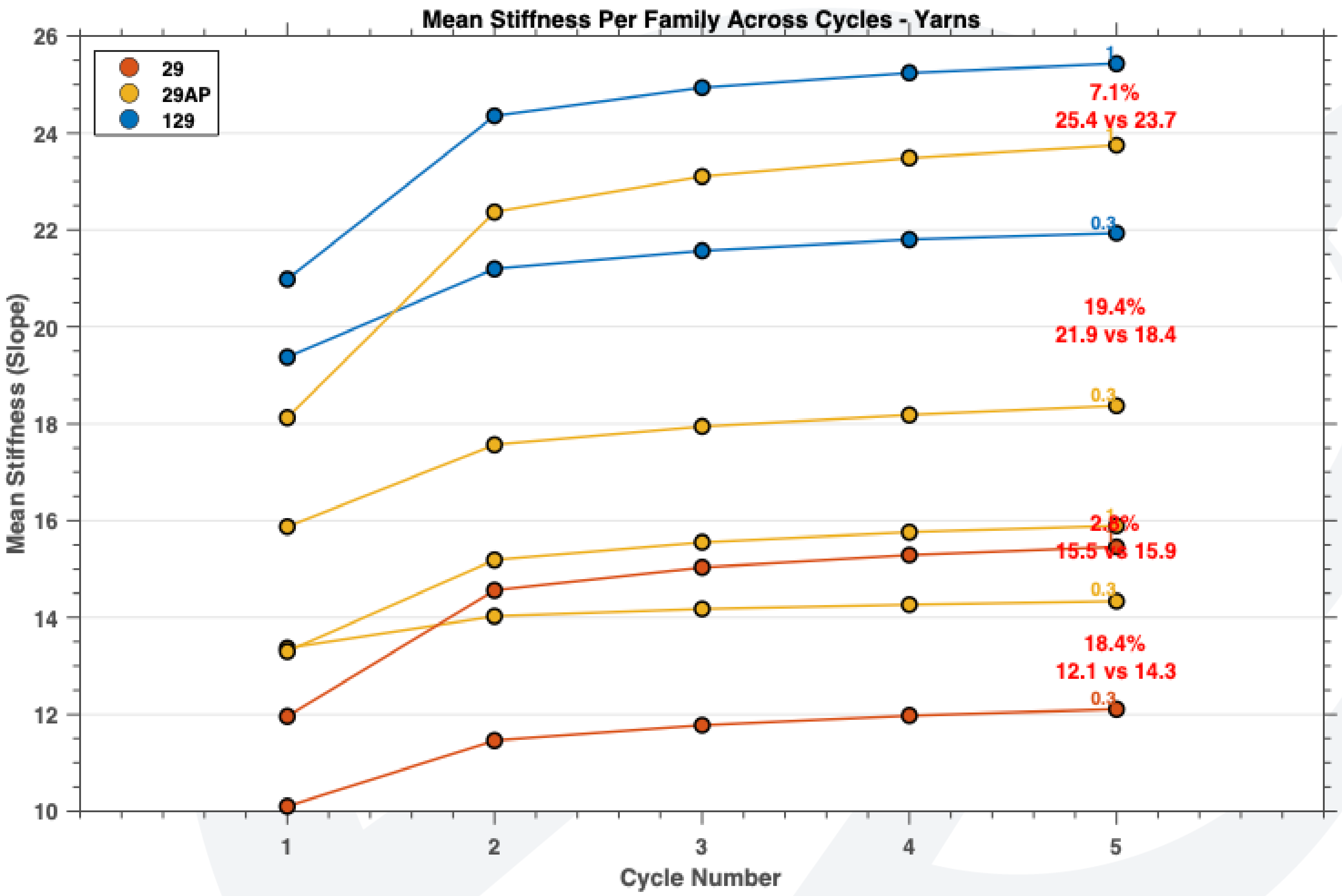
- Kevlar 129 is stiffer than Kevlar 29AP
- 7.1% stiffer at 100% load
- 19.4% stiffer at 30% load

For 500 lbf cord:

- Kevlar 29AP is stiffer than Kevlar 29
- 2.8% stiffer at 100% load
- 18.4% stiffer at 30% load

Stiffness of Kevlar:

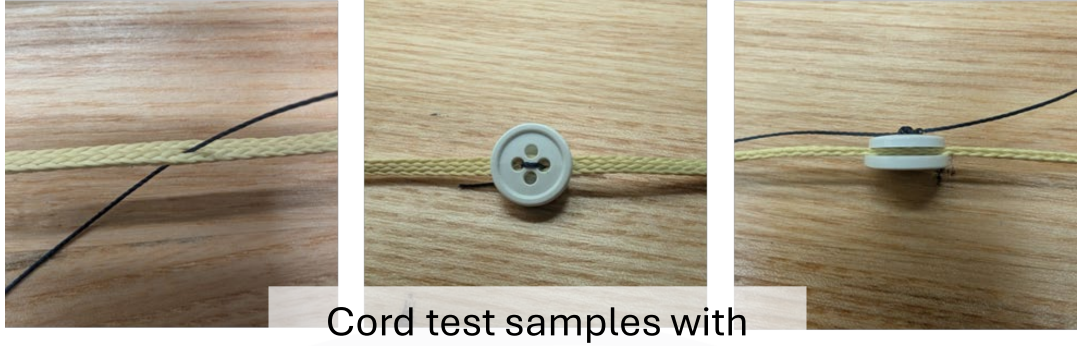
- Kevlar 129 > Kevlar 29AP > Kevlar 29
- This aligns with the Arclin yarn-level modulus data



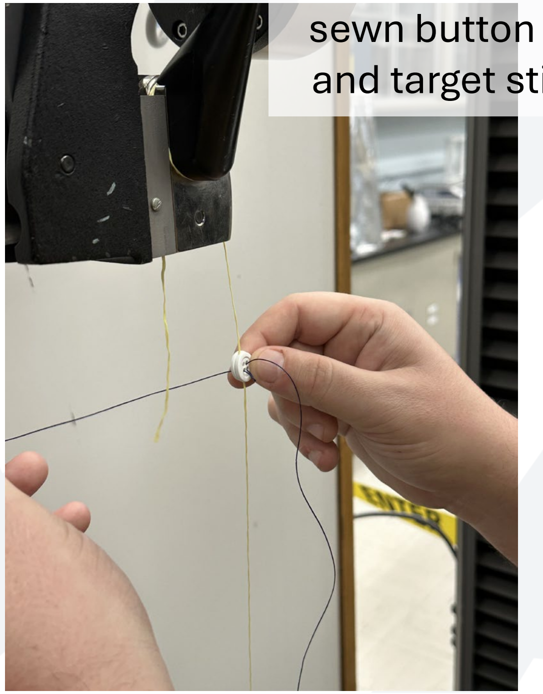
Photogrammetry

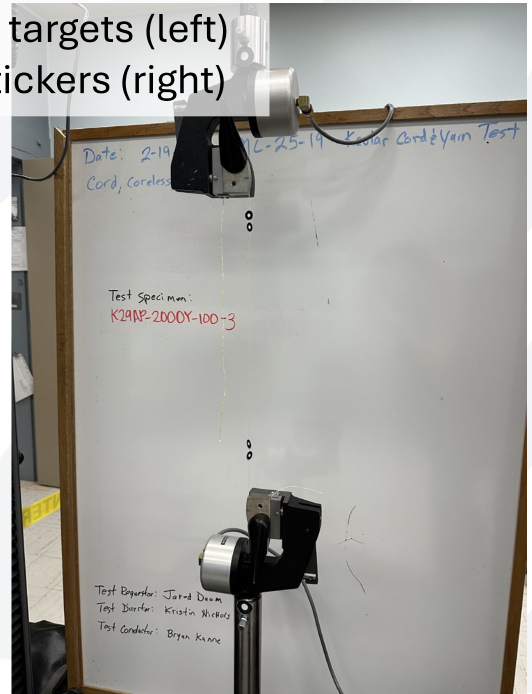
In addition to measuring sample elongation using crosshead displacement of the Instron machine, elongation was also measured using photogrammetry.

Photogrammetric-derived data showed good consistency with the Instron machine-derived data and was a valuable exercise in using an alternate method to gather elongation data of this type.



Cord test samples with sewn button targets





Yarn test samples with sewn button targets (left) and target stickers (right)

Summary & Conclusions

Tested 24 cord samples and 24 yarn samples

- 2000 lbf cord: Kevlar 29AP, Kevlar 129
- 500 lbf cord: Kevlar 29, Kevlar 29AP

Stiffness of Kevlar Types Tested for both cords and yarns:

- Kevlar 129 > Kevlar 29AP > Kevlar 29

Modulus test data are interpreted to show approximately 10% difference in elongation between Kevlar 29AP and Kevlar 129 and another 10% difference between Kevlar 29 and Kevlar 29AP.

Although this is a measurable change in modulus, the effect on parachute performance is likely small, particularly for non-primary structure elements of relatively small length.

This test campaign provides an example of the type of testing and analysis that parachute engineers could do to understand how material upgrades affect performance of their systems.

References

[1] “Cord, Fibrous, Aramid Braided”, PIA-C-87129D, 20 December 2013

[2] Kessler, G., “An Overview of Technical Textiles for Spacecraft Parachutes”, 28th Aerodynamic Decelerator Systems Conference and Seminar, London, United Kingdom, June 2026 (to be published)

[3] Fette, R., “Relaxation of Kevlar Braided Cords”, Master’s Thesis, School of Engineering Management and Systems Engineering of The George Washington University, June 2004

Thank You