

Properties of Fibers and Fabrics

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Abstract

This experiment tests the strength of threads, string and yarn made from different materials and then looks at the properties of fabrics made from these materials. In Part I, the breaking strength is measured using a simple experimental setup. This gives students a reference point for applications of different fibers in everyday use. In part II, the properties of fabrics are judged by the amount of static electricity that they can hold in dry and wet conditions. This provides students with a better understanding of the fabrics they encounter daily, the materials from which they are made, and an idea of their relative strengths. Each part of this module may be done independently if desired.

Module Objective

To help students understand the role of fibers in our society, including why different fibers are chosen for different applications, why fiber properties vary under different conditions (wet vs. dry, knotted vs. straight), and how natural and synthetic fibers compare. Part II considers properties that are related to the comfort of different fabrics made from fibers.

Student Learning Objectives: Students will be able to

- Describe property differences between natural and synthetic fibers
- Demonstrate that knots reduce the strength of fiber bundles.
- Show that some fibers have better and some have worse properties when wet
- Consider usage of fibers in actual applications based on property measurements
- Consider the importance of fiber properties in comfort when fibers are made into fabric

MatEd Core Competencies Covered

- 0.A Prepare tests and analyze data
- 6.A Apply basic concepts of mechanics
- 7.F Identify the general nature of fibers and fabrics
- 7.I Explain causes for differing materials properties
- 8.A Demonstrate the planning and execution of materials experiments
- 16.A Explain effects of processing and manufacturing variations on material

properties

Key Words: fibers, strength, flaws, fabrics

Type of Module: Lab experiments

Time required: Part I: One class period for lab, analysis and discussion

Part II: One class period for lab, analysis and discussion

Pre-requisite Knowledge: none

Target Grade Levels High school, college introductory undergraduate courses

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Part I: Strength of Fibers

Equipment and Supplies Needed

Strength testing machine—if no testing machine is available, please see the attachment for a simple testing machine that can be built by the instructor or by students as a special project.

Yarns and fibers of various types—one useful set is listed below with mass/unit length information for each:

100% Cotton (size 10) = 0.048 grams/ft.

100% Nylon (T26) = 0.016 grams/ft.

100% Silk = 0.0075 grams/ft.

100% Wool = 0.023 grams/ft

100% Rayon (floss) = 0.117 grams/ft.
 100% Rayon (40 wt.) = 0.007 grams/ft.
 100% Acrylic (4-ply) = 0.129 grams/ft.
 100% Acrylic (knit) = 0.093 grams/ft.
 100% Polyester = 0.0075 grams/ft.

Curriculum Overview and Notes for Instructor

Fibers and fabrics are stronger than their weight-equivalent bulk materials. Why? Some observations about fibers can help answer questions, For example,

- 1.) Fused silica fibers have strength as high as 2M psi.
- 2.) Flaws (or defects) in fibers result in stress concentration at the defect. Cracks initiate and propagate where stress is concentrated.
- 3.) Tensile strength increases with decrease in diameter. This is because the probability of finding a critical flaw or defect in the material decreases with decreases in diameter and length. Most synthetic fabric is processed (stretched) to obtain molecular orientation and varying amounts of crystallization, which greatly strengthens the fabric.

In this module, we will test threads, string, and yarn made from different materials for tensile strength by measuring the force required to break the material with a spring-loaded scale. In order to make a meaningful comparison we will have to compensate for the fact that the various strings and threads have different diameters or densities. Fibers (and particularly organic fibers) are commonly porous or hollow, and threads and strands are made from bundles of fibers. This makes it very hard to accurately measure the cross-sectional area of a small thread, and therefore to compute the absolute “engineering strain” or strength of a fabric. One way to get around this problem is to measure the force to break the fibers, and then to divide by the mass (weight) of a unit length of fiber. This gives a useful measure of the “relative strength” for a given mass of material. The mass/unit length information for the particular fiber samples proposed for use in this activity is given above in the listing of needed materials. (The denier or linear density is a common unit in the textile industry and refers to the number of grams per 9000 meters of thread or fiber).

A sample of the experimentally obtained breaking force and calculated “breaking force to mass ratio” for some materials are given in the table below.

Material	Mass/unit length	Force to Break	Breaking Force/Mass
Dry cotton	0.048 g/ft.	10 lbs.	208 lbs/(g/ft.)

Wet cotton	0.048	9	188
Cotton + knot	0.048	8.1	169 (broke at knot)
100% Silk	0.0075	1.8	240
100% Nylon	0.016	10.2	638
100% Wool	0.023	0.85	37
Acrylic 4-ply	0.129	12	93
Acrylic yarn	0.093	12.5	134
Rayon floss	0.117	11.4	97
Rayon (40wt.)	0.007	0.9	129
Polyester	0.0075	2.61	348

Notice that the acrylic yarn has the highest breaking force, about 12 lbs, however when the “Breaking Force/Mass” ratio is calculated then nylon and polyester appear to be much “stronger” even though the polyester thread broke at just 2.61 lbs. Other important observations to make are that the cotton string becomes weaker after soaking in water, and the cotton string with a knot was significantly weaker than similar cotton strings without the knot. Finally, note that both the rayon and acrylic threads appear to be “stronger” when the overall cross-sectional area (or mass/unit length) is smaller. This effect can be attributed to a decrease in the probability of finding a critical flaw or defect in a particular fiber bundle as the bulk or diameter of a thread is reduced.

What sample has the highest breaking force? (The acrylic 4-ply yarn has the highest weight per unit length, and will probably require the most force to break.) What sample has the highest “breaking force to mass” ratio? (Nylon has a very high breaking force, and yet has a much lower mass per unit length than many of the other sample materials. The “breaking force to mass ratio” for nylon should therefore be very high compared to most materials.) Does a knot in a string or thread decrease the force that is required to break the material? (The tensile stress, σ , on a fiber is measured by the force, F , divided by the area, A , of the fiber face such that $\sigma=F/A$. A knot is an example of an intentional defect that concentrates stress and breaking will tend to initiate at the knot with less applied tension or breaking force).

How does water affect the breaking force for natural and synthetic materials? (Man-made or synthetic materials will generally be less porous and will not absorb water as readily as natural fabrics. Exposure to water may therefore

have less noticeable effects on the synthetic fabrics. Before the advent of synthetic fabrics, silk was one of the strongest fabrics that was available, and was used to make parachutes because of its high strength to weight ratio. Mountain climbing ropes are typically made of nylon, and should not have knots in them if possible. Ropes should also be reliable in wet weather and resistant to rotting, so that nylon synthetics appear to be a better choice than cotton or natural materials. Special purpose ropes such as that used for water skiing should float. Polypropylene ropes are used for this purpose. Spider webs and silk have been studied by a number of researchers for their remarkable natural properties. The tensile strength of spider silk is greater than the same weight of steel and has much greater elasticity. Its microstructure is under investigation for potential applications in industry, including bullet-proof vests and artificial tendons. Researchers have used genetically modified mammals to produce the proteins needed to make this material.

One could also go further with the concepts in this experiment. For example, the experimental apparatus and experiment could be enhanced by putting a ruler behind the specimen (fabric) as it stretches thereby measuring the elongation as well as the load. A crude stress vs. strain curve could be developed with the data points. One student would have to call out the load while another would have to keep an eye on the elongation or stretch. Some reference to an appropriate ASTM specification might be helpful to see how standards work. An old trick can be used to integrate under the curve. The data can be plotted on graph paper and one square inch could be cut out and weighed. The curve itself (stress vs. strain) can then be cut out and weighed. A weight to area ratio can be calculated and the energy to break can be computed using the appropriate units. The properties of stress vs. strain play against each other particularly well in fish line materials since you want some give to the fish line. These can be excellent topics to explore along with the idea of energy to break since it leads into many discussions about materials that are tough vs. those that are strong, and how to choose them for specific applications. For example, elastomers as compared to brittle materials like ceramics.

Module Procedure

1. Test each of the threads, strings, and yarns for breaking force with the spring loaded scale.
 - a. test cotton strings both dry, and after soaking in water
 - b. test dry cotton string or thread with a tight knot in the middle of the string
 - c. test a synthetic material such as nylon or polyester under wet and dry conditions, and with a knot in middle of fiber

2. Make a table with columns for 1.) material type, 2.) force to break material (lbs), 3.) mass/unit length (g/ft.), and 4.) "breaking force to weight ratio" lbs/(g/ft.) with observations or comments.
3. Have the students determine which sample has the highest breaking force. Compare this to the sample with the highest "breaking force to mass ratio." Which is more important for applications of fibers?
4. Ask the students to consider fibers
 - a. Used as fishing line—which fiber would be best to use? Why?
 - b. Used to make a mountain climbing rope—which fiber would you use? What effect would a knot in the rope have on strength?
 - c. Used for a water ski rope—what properties would you want in a water ski rope as opposed to other types of ropes?
 - d. Used to make fabric—which fiber would be best to use? Why?

Part II : Use of fibers in fabric for clothing

Equipment and supplies needed:

Fluke 85 voltmeter or similar high impedance voltmeter with a peak dc voltage setting.

Cotton, polyester, acrylic, rayon, nylon, wool, and acetate fabrics.

Curriculum overview and notes for instructor

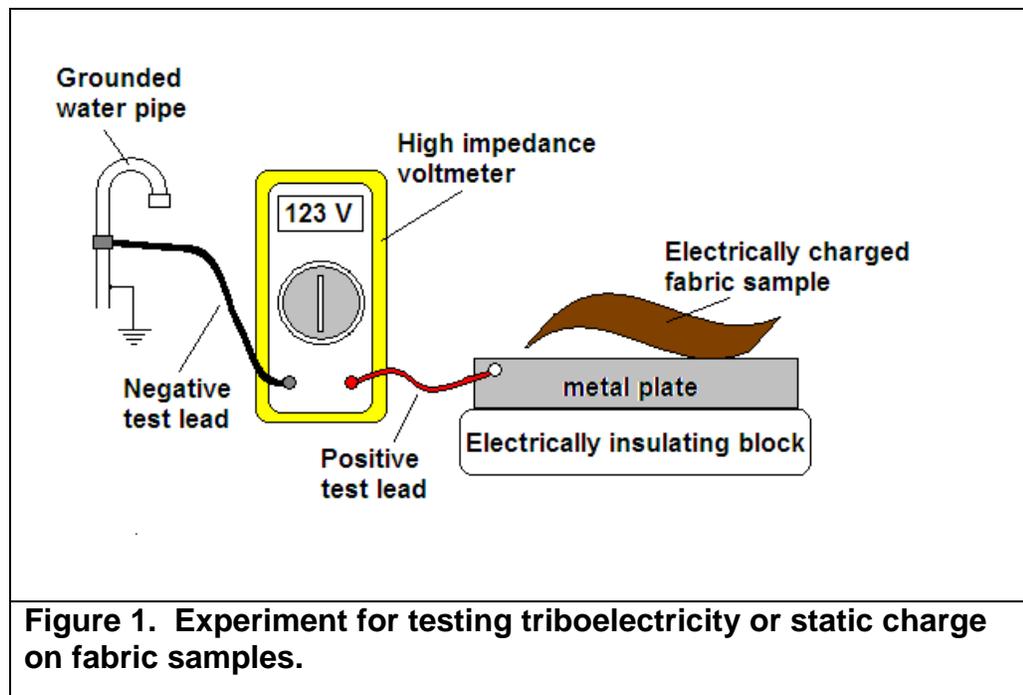
Comfortable clothing has to do more than just keep us warm in cold weather and relatively cool in hot weather. Two major properties that determine the physiological comfort of a fabric are breathability and static charge (triboelectric) susceptibility.

Under average conditions, an adult human being produces about 1.0 liter/day of perspiration (sweat) that needs to be removed. When overheated, the body's main temperature regulation mechanism is by perspiration, so the breathability of a fabric is not just a comfort factor. Linen (flax) fibers both absorb and wick well, so that these fabrics are preferred in hot climates. Olefin fabric, a waxy-synthetic, also wicks well and makes comfortable underwear and sportswear.

Static Charge, or triboelectricity, is built up by friction between two electrically non-conductive surfaces. Static charge build-up is an inverse function of a fabric's absorbancy, because moisture conducts away electric charge.

Module procedure

1. Connect the negative lead of the voltmeter to an effective earth ground such as a water pipe. Connect the positive lead to a metal plate that is electrically insulated from ground. This experiment works best on days when atmospheric humidity is low.
2. Rub each fabric against hair on arms or head, then measure the relative build-up of static charge by placing the fabric sample on the electrically insulated metal plate.
3. Rank the fabrics from most positive to most negative static charge build-up generated from rubbing on hair.
4. Discuss what this means about comfort of fabrics. Relate it back to the strength discussion in Part I.



Supporting Documentation

Please refer to the attachment for details on a simple home-built testing machine for fiber testing.

Acknowledgments

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References

http://en.wikipedia.org/wiki/Fabric_structure

This is a comprehensive reference that discusses fabric structures and materials basics.

http://en.wikipedia.org/wiki/Synthetic_fiber

This reference provides a historical summary of synthetic fibers.

http://www2.dupont.com/Kevlar/en_US/index.html

This commercial site gives many interesting examples of applications including bullet proof vests for high performance synthetic fibers.

<http://www.fabrics.net/Microfibers.asp>

This site is an interesting collection of fabric facts and applications.

Evaluation Packet

Student evaluation questions (discussion or quiz):

1. Describe property differences between natural and synthetic fibers
2. Demonstrate that knots in fibers are detrimental to performance
3. Show that some fibers have better and some have worse properties when wet
4. Discuss usage of fibers in actual applications based on property measurements
5. Show how to demonstrate the importance of fiber properties in comfort when fibers are made into fabric.

Instructor evaluation questions:

1. At what grade level was this module used?
2. Was the level and rigor of the module what you expected? If not, how can it be improved?
3. Did the lab work as presented? Did they add to student learning? Please note any problems or suggestions.
4. Was the background material provided sufficient for your background? Sufficient for your discussion with the students? Comments?
5. Did the lab generate interest among the students? Explain.
6. Please provide your input on how this module can be improved, including

comments or suggestions concerning the approach, focus and effectiveness of this activity in your context.

Course evaluation questions (for the students)

1. Was the lab clear and understandable?

2. Was the instructor's explanation comprehensive and thorough?
3. Was the instructor interested in your questions?
4. Was the instructor able to answer your questions?
5. Was the importance of materials testing made clear?
6. What was the most interesting thing that you learned