1 Tensile Test

CORE LAB

Many biological materials – from skin to ligaments to blood vessel walls – carry tensile loads. To function properly, these natural structures and their engineered replacements must have suitable tensile strength and stiffness.

Tensile testing (Fig. 1) provides one of the best ways to measure these properties because it is simple and provides a wealth of information (Fig. 2). In this test, a specimen of material is cut into a specific shape, the ends of the specimen are held in an attachment system, and the specimen is stretched in a prescribed manner as the succession of associated loads is recorded. This data can be converted into stress-strain information and used to determine standard properties such as material stiffness, strength and ultimate strain. Interestingly, the stiffness of many biomaterials change as they are stretched and this change can be important to their function.

These properties can be useful for understanding how loads are carried in the body, for identifying and characterizing disease states, and for designing biomaterials for prostheses or replacements. Associated technologies that require these properties include elastography, modeling of organ positioning for radiation therapy, and virtual environments for surgical planning and rehearsal.
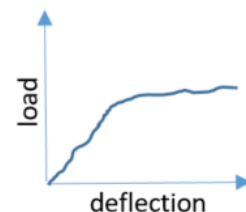

Fig. 1 – A Tensile Test

Fig. 2 – Data from Test

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Background

One of the most interesting materials to test in tension is skin. Skin serves as a barrier to invasion by microbes, germs, and other foreign materials and is one of the most important organs of the body. It helps regulate body temperature and permits the sensations of touch, heat, and cold. Human skin is the largest organ and covers a total area of approximately 2 square meters.

Skin is flexible, tough, and strong. It can be pulled and stretched to a great extent without damaging it. The strength and flexibility of the skin comes from two structures found in the dermis layers: collagen and elastin. Collagen is a fibrous protein, and it gives skin strength and holds its various structures together. In contrast, elastin is a crenulated protein and it gives skin its flexibility and elasticity. During normal activities, human skin can stretch by as much as 20%,

Tensile properties of skin depend on age, gender, and anatomical region. Both collagen and elastin fibers weaken as we age and using moisturizers, eating healthy food, and exercising will help to ameliorate this process. Tensile testing of skin is useful for assessing the effects of aging, disease, or restorative interventions.

Instructors Notes

This Laboratory allows students to learn about the tensile properties of skin, a synthetic replacement such as SynDaver, or a biomaterial such as rubber.

If suitable specimens are used, such as those provided in the CellScale specimen kit, students can also explore the effects of specimen anisotropy on stress and strain curves and how local strain can be analyzed.

This lab is the first core lab in a series. It can stand alone or be used with the other two core labs in this series: compression testing and 3 point bending.

This document is written in color-coded blocks or modules. Green boxes are for students. Information for instructors and TAs is in orange and includes specimen preparation, sample data, and alternative materials. Optional modules are shown in purple.

As noted in this document, this lab addresses several of the engineering accreditation criteria and outcome goals.

Motivation

A tensile test is the most common method of determining two basic material characteristics: stiffness and strength. This lab will provide insight into how this testing is done and how the results of a specific test are used to determine the specimen's mechanical properties.

A tensile test involves applying displacements to stretch the specimen while measuring the corresponding forces. The specimen geometry combined with the displacement and force data can be used to calculate geometry-independent stress and strain data.

An Interesting Fact

The skin has its own bacteria microbiome of over 1000 species! Skin bacteria protect humans from pathogenic invaders and help the immune system maintain its balance between effective protection and damaging inflammation.

Learning Goals

- To understand the requirements to perform a tensile test.
- To operate a mechanical test system.
- To understand and describe the material properties of the specimen.
- To estimate material parameters from experiments.
- To understand local strain analysis.
- To understand the anisotropy of the material.
- To understand shape effects.

Safety Notes

- For your safety, a lab coat, safety glasses, and surgical gloves must be worn during this lab.
- Ensure that the area around the moving actuator is clear before commencing test protocols. Keep hands clear of moving parts for the duration of the test.
- You can stop a test at any time by turning off the switch on the front of the testing device or by clicking ❌ on the toolbar, or by selecting Stop from the File menu.

Equipment

- UniVert materials testing system.
- 200N load cell and spring closure tension grips.
- SynDaver artificial skin cut in desired shapes.
- Measurement calipers.

An Interesting Fact

The thinnest skin on your body is found on your eyelids (0.02mm). The thickest skin is found on your feet (1.4mm).

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Specimen Preparation

The SynDaver artificial skin sheet must be cut into specific dimensions using a die and arbor press. To perform a tensile test, materials are often cut into dumbbell-shaped specimens. The shape features rounded edges (fillets) in order to avoid undesirable stress concentrations close to the grips that hold the specimen. Therefore, the specimen failure will occur in the narrower gage region.

- Lay the skin sections flat on the cutting mat
- Use the specimen cutting die and arbor press to prepare 3 tensile specimens. Be sure to keep the skin on the cutting mat to avoid damaging the die cutting edge.
- Optional: To investigate the effect of material anisotropy, cut 3 specimens in X and Y directions.
- Optional: Use permanent marker to draw dots on the specimen.
- Optional: Use scissor to cut a square shape.

Specimen Measurements

To perform a tensile test, materials are cut into a testable geometry. Often, the materials are cut into dumbbell shape with different dimensions.

1. Collect three samples of each of the following:

2. Measure thickness and width of specimens three times using the caliper.

Specimen Measurements (Local Strain)

The effects of how strain may vary from place to place on a specimen during testing can be investigated by adding ink dots to specimens as shown below. Local strains can be determined in the data analysis step by tracking the locations of these dots in collected images.
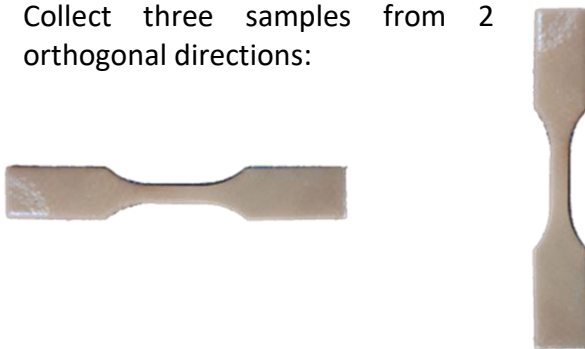

1. Measure thickness and width of specimens three times using the caliper.

Specimen Measurements (Anisotropy Effects)

The effects of material anisotropy can be investigated by collecting specimens from different orientations.

1. Collect three samples from 2 orthogonal directions:

2. Measure thickness and width of specimens three times using the caliper.

Specimen Measurements (Shape Effects)

The effects of specimen shape can be investigated by collecting specimens with different shapes. Here we will compare testing dumbbell versus rectangular shaped specimens.
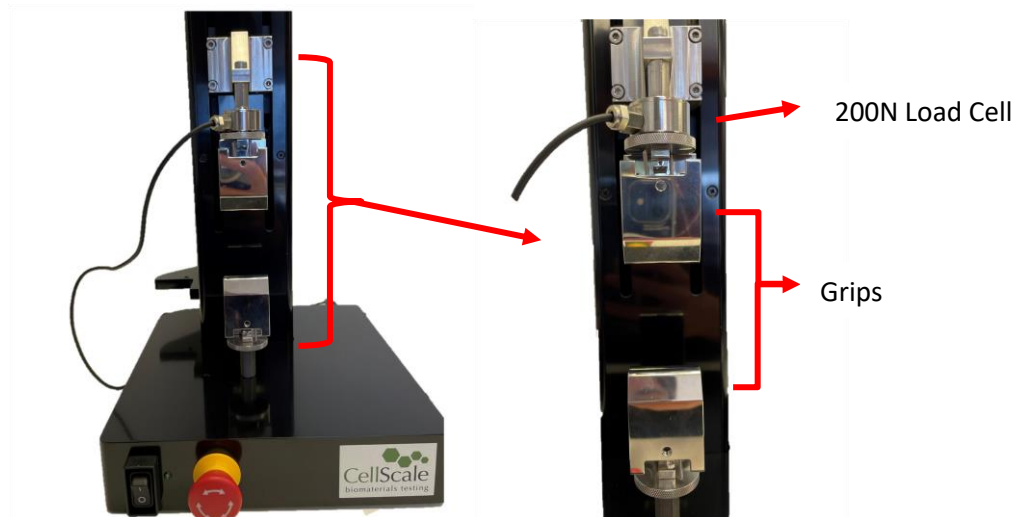
1. Collect three samples of each of the following:

2. Measure thickness and width of specimens three times using the caliper.

Machine setup

Before starting this lab the UniVert testing machine must be set up with the following:


Refer to Appendix D in the CellScale UniVert User Manual which outlines this process in detail.

Note: Choose a load cell with a capacity that is higher than the failure load of the material you are testing. Stronger or thicker specimens may require a higher capacity load cell. Also, certain materials may require the use of sand paper to prevent the specimen from slipping out of the grips.

Procedure – Tensile Testing

Tensile test is performed on a specimen by applying prescribed displacements to its extremities and measuring the resultant forces. This test illustrates engineering material parameters by providing the Stress vs. Strain curve.

1. Open the UniVert software by clicking on the icon.

2. Begin a new test (File, Collect New). Use the template "CellScale Tensile Lab". Use an appropriate name for your test and store your data in a folder on the local hard drive.
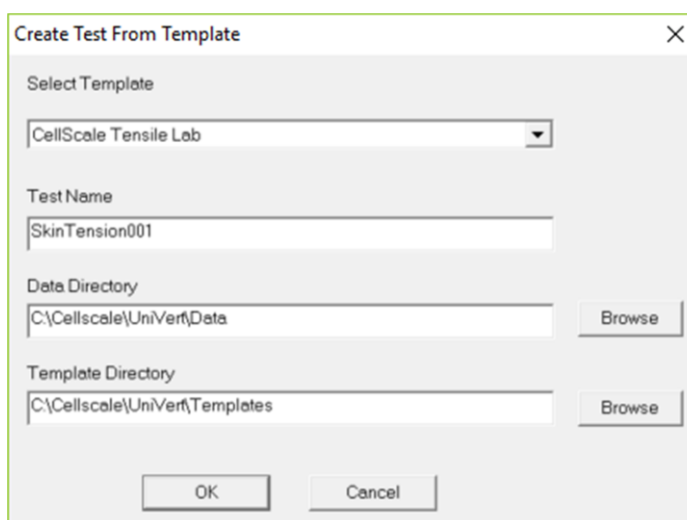
3. The main control screen should open and the information dialogue on the left side of the screen should display System Ready!

4. Reset the actuator by clicking Tools, Reset Actuator or click on the ⟳ icon. Resetting the actuator will ensure that the system position is correct.

5. If the system setup has changed (grips, riser, load cell) then a zero position calibration should be performed. Refer to Section 8 in the CellScale UniVert User Manual which outlines this process in detail

6. Zero the load cell with no load applied by clicking Tools, Zero Load Cell or clicking on ⚖ icon. Zeroing the load cell will remove any offset forces such as those from the weight of the upper grips.

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7. Place the sample on the centre of the lower grip.
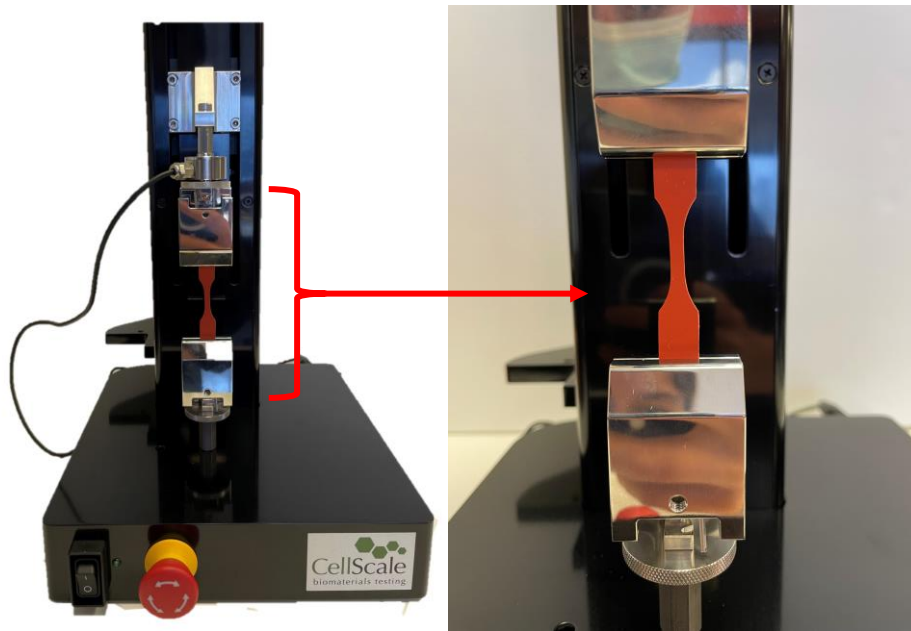
8. Lower the upper grip until it is almost gripping the specimen by using the jog arrow icons on the actuator control window. You can control the speed.

The Current Size (separation between the grips) is displayed on the left panel of the screen.
An alternative approach to lower the upper grip is to enter the desired size in the

Specified Size field (at the top of the screen) and use the move to size function by clicking Tools, Move to Specified Size or clicking on the icon.

9. Using a slow jog speed (about 3) continue to lower the upper platen using the jog arrows until it is just touching the specimen. Check that the applied force (shown on the left panel) is less than 0.2N (this threshold value changes with different materials). Grip the specimen with the upper grip.

10. Run the test by clicking File, Execute or clicking on the ▶ icon. Observe the live video and graphing displays to make qualitative observations about the test.

11. Wait until the test finishes. The test can be stopped early by clicking on the ✖ icon.

12. Remove the specimen and repeat the test procedure for the remaining specimens.

13. Clean up the work area as instructed.

Data Analysis

1. Open each of the output files (*.csv) in excel. These are located in the test folder selected when the test was setup using Collect New

2. Combine the data into a common workbook with multiple worksheets and save as a *.xlsx file.

3. For the first test, create a new column to the right of the existing columns and title it Strain. Populate this column with the strain values defined by Equation 1.

$$\varepsilon = \frac{\Delta L}{L^\circ} \qquad\qquad (1)$$

Where ΔL is deformation and L° is grip to grip length.

4. Create a second new column to the right of the existing columns and title it Stress. Populate this column with the stress values, as defined by Equation 2. Watch the units!

$$\sigma = \frac{F}{A^\circ} \qquad\qquad (2)$$

Where F is force and A° is the initial area of the middle region.

5. Generate a line scatter plot with Strain on the X-axis and Stress on the Y-axis.

6. Approximate the linear region of the curve and reduce the source data to display only the linear region. Add a linear trend line to this graph and display the equation on the graph. The slope trend line represents the stiffness of this specimen. For a linear material, the stiffness is referred to as Young's Modulus.

7. Identify the stress and strain values at which the curve becomes non-linear. This is the yield point, the point at which the material is still stretching but also beginning to fail. Note the yield stress (σ_y) and the yield strain (ε_y).

8. The maximum force value is referred to as the Ultimate Tensile Strength (σ_{UTS}).

9. A sharp decline over a narrow range of strain is indicative of a brittle material. A flat plateau followed by a slow decline is indicative of a tough material. Note the strain at which the material fails completely (the force returns to zero), ε_{max}.

10. Perform steps 3-9 on the remaining specimens.
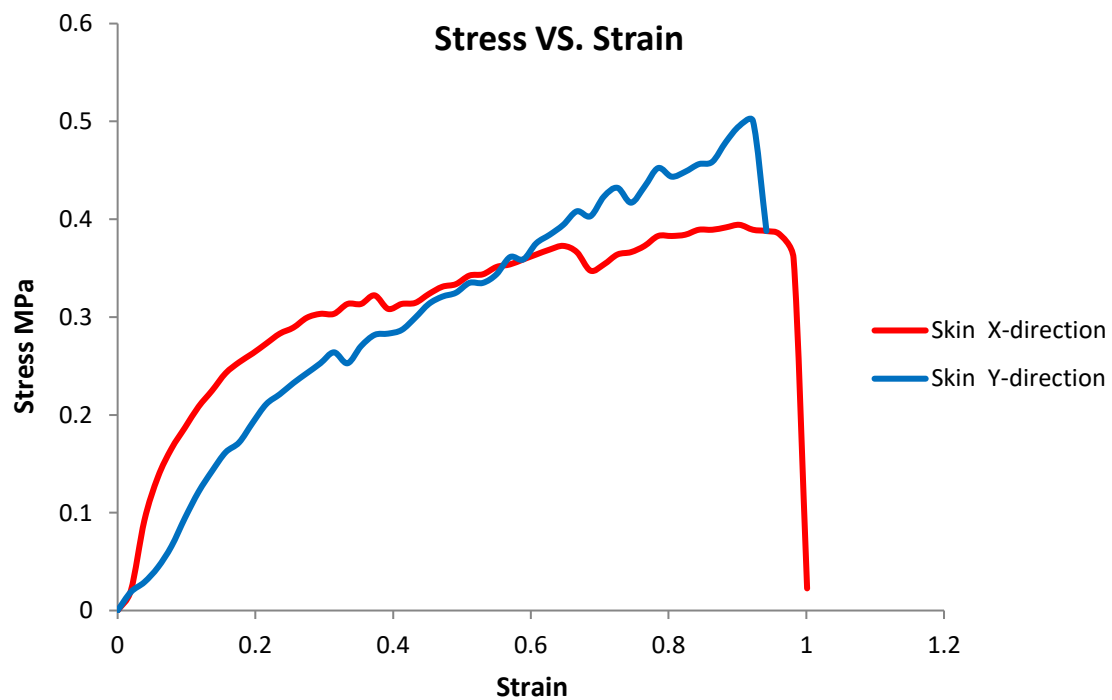
Sample Data

Synthetic skin specimen sample data:
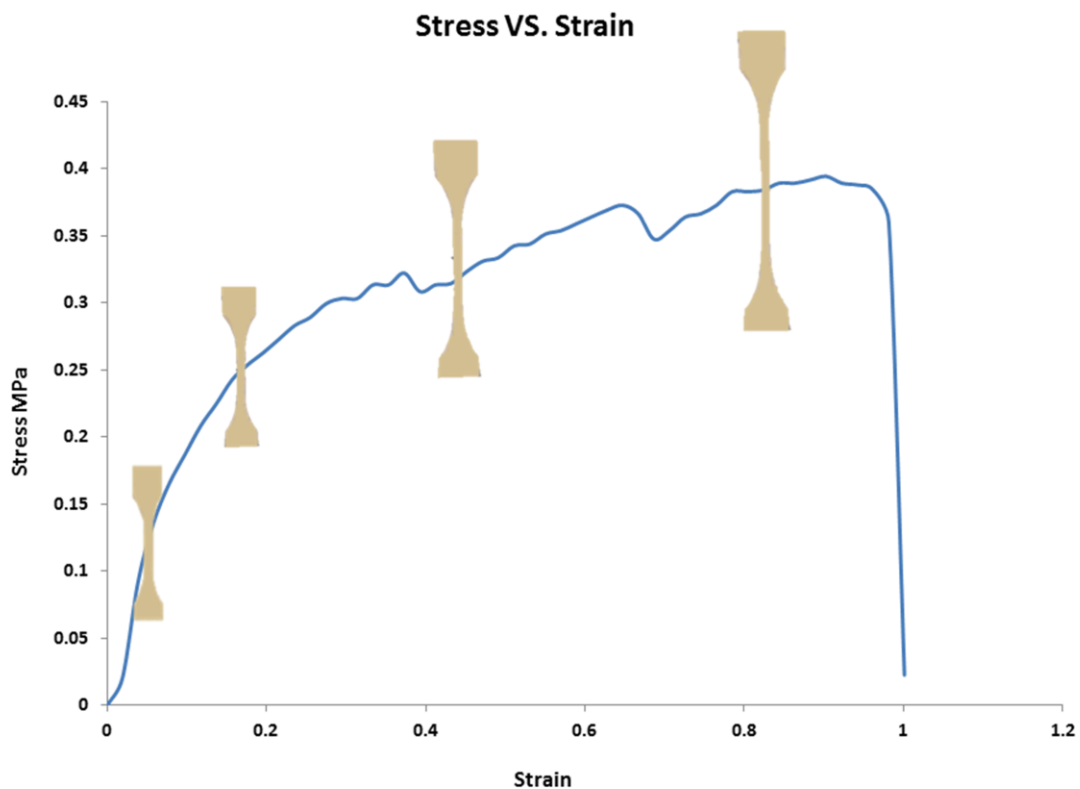
Synthetics skin local strain Specimen sample data:
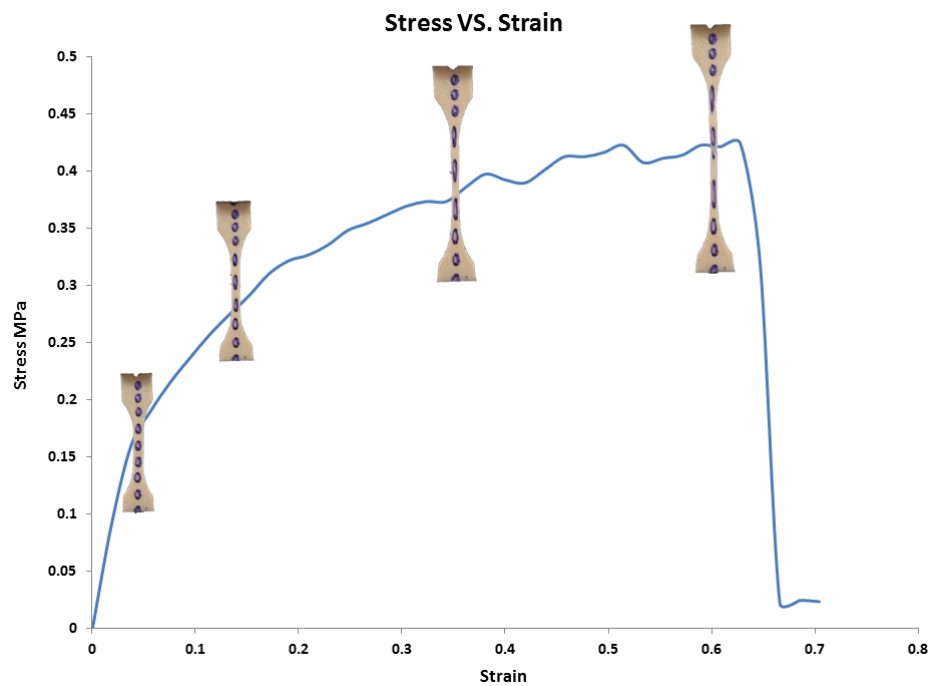
Synthetics skin anisotropy sample data:

Analysis – Numerical Data

- For each specimen:

    1. Plot the stress vs. strain graph.

    2. Calculate the deformation, $\Delta L(t)$, the engineering stress $\sigma(t)$, and engineering strain $\varepsilon(t)$.

    3. Calculate the Young's Modulus (E).

    4. Calculate the yield stress (σ_{yield}) and yield strain (ε_{yield}).

    5. Calculate the ultimate stress (σ_{max}) and ultimate strain (ε_{max}) corresponding to fracture.

    6. Work done is defined as force × distance, usually given in terms of kN.m. This value can be found for the various samples tested in this experiment by taking the area under the Force vs. Displacement curve, which is linearly related to the Stress vs. Strain curves already plotted. Calculate the work done to fracture each specimen.

- Calculate the average and standard deviation for (E), (σ_{yield}), (ε_{yield}), (σ_{max}), and (ε_{max}) for similar specimens.
- What is the percentage error of Young's Modulus giving that $E_{theoretical}$ is 1 MPa?

Reflection

1. What information did you learn about skin today? Thinking about the functions that skin serves for the body, what mechanical properties do you think are important?

2. What are some of the sources of error in the testing? How could they be minimized?

Conclusion

1. List the 3 most important things that you learned by carrying out this lab.

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Applications

1. In terms of the biological function of the skin, which of its mechanical properties do you think are the most important? Why? You might list some properties that could be measured with simple tensile testing and some that could not.

2. Identify at least one medical condition that changes the mechanical properties of skin. What are the symptoms of the conditions?

Alternative Materials

- Artificial tendon, fat, cardiac tissue.
- Chicken skin.

Engineering Accreditation Criteria

Student outcomes have become an integral part of engineering education, and specific ABET and CEAB outcomes the labs can help address are shown below.

Accreditation Board for Engineering and Technology General Criterion

1. An ability to apply knowledge of mathematics, science, and engineering
2. An ability to design and conduct experiments, as well as to analyze and interpret data
3. An ability to identify, formulate, and solve engineering problems
4. An ability to use the techniques, skills, and modern engineering tools necessary for engineering practice

Canadian Engineering Accreditation Board Graduate Attributes (CEAB)

1. A knowledge base for engineering: Demonstrated competence in university level mathematics, natural sciences, engineering fundamentals, and specialized engineering knowledge appropriate to the program.
2. Problem analysis: An ability to use appropriate knowledge and skills to identify, formulate, analyze, and solve complex engineering problems in order to reach substantiated conclusions.
3. Investigation: An ability to conduct investigations of complex problems by methods that include appropriate experiments, analysis and interpretation of data and synthesis of information in order to reach valid conclusions.
4. Use of engineering tools: An ability to create, select, apply, adapt, and extend appropriate techniques, resources, and modern engineering tools to a range of engineering activities, from simple to complex, with an understanding of the associated limitations.