MS 101 – Autumn 2023 – Project Updated on 26th October ~~(ME Part)~~

~~Automatic tensile~~ Tensile testing apparatus to break ~~paper~~ foam board strips

Goal:

In this project, you will design and build, ~~an automated tensile testing machine~~, for pulling a thin sheet of foam material, until failure.

Background:

Tensile testing of engineering materials is done to extract their stress-strain response, which is the normalized force-displacement response. Here, the force and displacement are normalized by area and length, respectively. If the stress-strain response is linear, then we often model it as Hooke's law (not a law of physics, but a model that captures the region of linear response for most engineering materials). However, most engineering materials show a linear response followed by a nonlinear region, with lower stiffness (stress/strain ratio). A typical stress vs. strain curve is shown in figure 1(a), where the initial portion is linear followed by a nonlinear region with positive slope. As the specimen is continuously pulled, at some strain, the stress starts decreasing. This is due to initiation of damage/failure in the material, often correlation to the observation of necking (non-uniform reduction in the cross-section of the sample perpendicular to the pulling direction, see figure 1(a)) in the sample. Pulling the specimen further, will break it into two parts, referred to as complete failure. The stress and strain at failure are called, failure strength and ductility, respectively. This uniaxial (one dimensional stretching of the sample) tensile test is often conducted using a universal testing machine (UTM), see figure 1(b). [Note: There an umpteen number of videos on Youtube related to UTM and tensile testing. Please take a look to understand on how they operate.]

The normal testing process involves, manually positioning the specimen and gripping it to load in tension. ~~In this project, using linear motion and appropriate mechanical elements, you will position the specimen under the grips, as well as, grip one end of the specimen, automatically. The automatic loading saves time and enables repeatable testing of specimens without human intervention, similar to an assembly line in manufacturing industries.~~

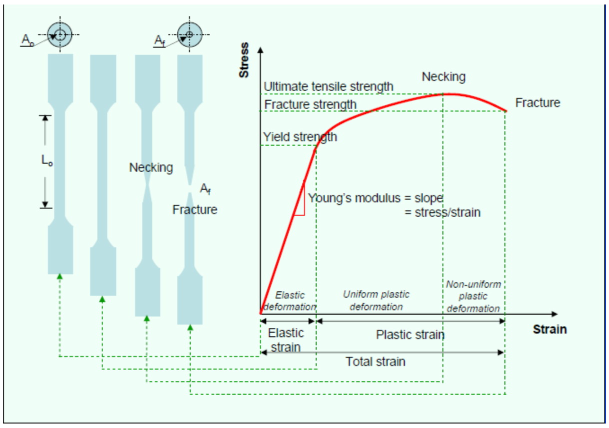
Objective:

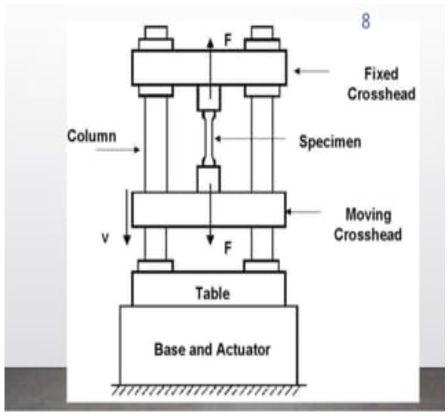
Overall objective is to obtain a stress vs. strain curve of a ***foam sheet specimen*** *given to you using the tensile test setup you design and build.* The test standard used in industry (ASTM-D638) is attached. Important aspects of this test method and specimen design will be covered in the class related to the project.

To fulfill the core objective, you need to complete the following milestone~~s~~, preferably in the order given.

1. Pull the flat sample, shown in figure 2, along its length using a motor connected to a leadscrew until the sample breaks into two parts. Measure the displacement and load, using sensors and Arduino board you configure and program. Employ the measured data to construct a stress vs. strain curve of the sample. Note the specimen is shaped in such a way that the gripping area on either end should be outside the region defined by the dimension D. This will ensure that the specimen will always break in the center rectangular region, with the force/stress distribution uniform along its length. This is the reason why it is called a uniaxial tensile test.

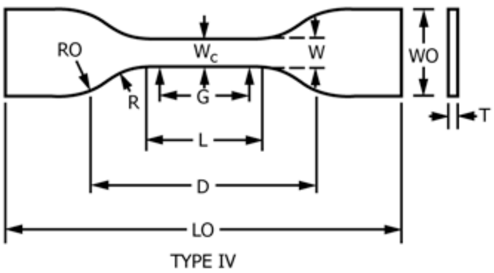
2. ~~Grip the sample on one end tightly using a mechanism that is driven by a motor and a leadscrew. The other end of the sample is fixed either to the linear translation stage built in milestone 3 below, or fixed to the table or fixed crossed as shown in the figure 1(b).~~
3. ~~Automatically position the given flat sample shown in figure 2(a), under the mechanical grips using a linear translation stage driven by a motor and a leadscrew.~~

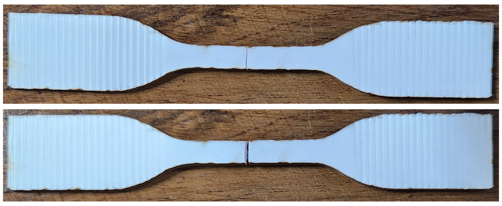




1(a) 1(b)

Figure 1: (a) Stress-strain response of a ductile material under uniaxial tension until failure; and (b) Schematic a Universal Testing Machine (UTM).





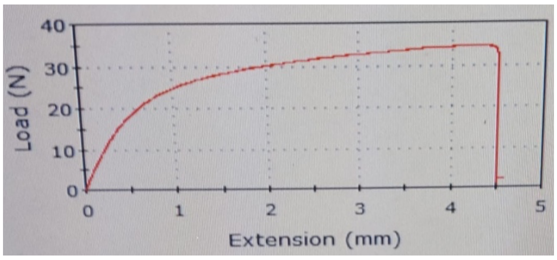
2(a) 2(b)

Figure 2: (a) Specimen geometry with various dimensions indicated as per ASTM-D638, and (b) actual specimen fabricated using laser cutting machine and tested in tensile until failure. Note the geometrical dimensions are given in the table below.

Specimen Dimensions for Thickness, *T*, mm (in.)[A]

Dimensions (see drawings)	7 (0.28) or under		Over 7 to 14 (0.28 to 0.55), incl	4 (0.16) or under		Tolerances
	Type I	Type II	Type III	Type IV[B]	Type V[C,D]	
W—Width of narrow section[E,F]	13 (0.50)	6 (0.25)	19 (0.75)	6 (0.25)	3.18 (0.125)	±0.5 (±0.02)[B,C]
L—Length of narrow section	57 (2.25)	57 (2.25)	57 (2.25)	33 (1.30)	9.53 (0.375)	±0.5 (±0.02)[C]
WO—Width overall, min[G]	19 (0.75)	19 (0.75)	29 (1.13)	19 (0.75)	...	+ 6.4 (+ 0.25)
WO—Width overall, min[G]	...	...	...	...	9.53 (0.375)	+ 3.18 (+ 0.125)
LO—Length overall, min[H]	165 (6.5)	183 (7.2)	246 (9.7)	115 (4.5)	63.5 (2.5)	no max (no max)
G—Gage length[I]	50 (2.00)	50 (2.00)	50 (2.00)	...	7.62 (0.300)	±0.25 (±0.010)[C]
G—Gage length[I]	...	...	...	25 (1.00)	...	±0.13 (±0.005)
D—Distance between grips	115 (4.5)	135 (5.3)	115 (4.5)	65 (2.5)[J]	25.4 (1.0)	±5 (±0.2)
R—Radius of fillet	76 (3.00)	76 (3.00)	76 (3.00)	14 (0.56)	12.7 (0.5)	±1 (±0.04)[C]
RO—Outer radius (Type IV)	...	...	...	25 (1.00)	...	±1 (±0.04)

Figure 3(a) below shows a commercial UTM machine used for testing the foam sample mentioned in the objective. The specimen is gripped in the lower fixed jaw and the upper moving jaw, as seen the closeup view. Figure 3(b) shows the load vs. displacement curve obtained from this tensile test, where there is a initial linear portion followed by a nonlinear region and then a linear region. The sudden drop in the load at the end is an indicator of failure of the specimen into two parts. You will use data from figure 3(b) to design your leadscrew, nut and gearbox, as well as choose the motor power/speed.



3(a)

3(b)

Figure 3: (a) UTM with specimen gripped for vertical tensile loading. A closeup view shows the specimen gripped between the jaws of wedge type grips, and (b) load-displacement curve recorded by the instrument connected to this UTM.

Mechanical Components:

Some important mechanical components that are required to build this machine to position the sample, grip it and then load it to failure are:

(a) Linear drive mechanism (Leadscrew and nut): This combination you have already seen in the lathe machine. It was used to give feed as you did the turning process. The leadscrew is used to convert rotary motion to linear motion. As you are going to use a motor to drive all the 3-axis in the machine, you will need this kind of mechanical component (assembly of leadscrew and nut). As you have already been told during thread cutting that the pitch of the leadscrew decides the axial displacement per rotation. So, using the encoder on the motor you will be able convert the number of rotations to linear motion to get applied displacement on the specimen. There are other mechanisms used to convert rotor to linear motion. You are welcome to pursue them but, this combination is the simplest and used everywhere.
https://fractory.com/lead-screws/

(b) Torque conversion mechanism (gearbox or belt-drive): Your motor (low cost) has limited torque but, higher speed. To drive a leadscrew in a nut, you have to overcome the friction, which requires higher torque. The gearbox as well as belt-drive shown on the lathe are two commonly used torque converters. You will need to design your own gearbox or belt-drive to extract the required torque from the motor to drive the leadscrew, at the expense of speed. You may want to visit the lab and see how the combination works and use online tools to get the adequate torque. Often the term gear-ratio is used to define the torque amplification factor. In your setup, you can design the spur gear based gearbox (the one in the lathe machine), and fabricate them using laser cutting machine. You can use tools such as https://geargenerator.com or use tools available in Fusion360 for which the link to the addon software as well as the installation files are available in the project folder.

(c) Alignment mechanism (Guide rods): While the leadscrew drives the grips apart to break the sample, you need some mechanism to keep them all aligned. In automation of assembly lines as well as high precision plan motion systems, linear slides of various kinds are used driven by leadscrew. The slides move in a line guided by straight rods usually over linear bearings. But, in your project, you may just choose simple have linear guide rods to ensure alignment, at the expense of higher friction.

Finally, the CAD model of a simple design satisfying all three objectives of the project is shown in Figure 4 below. You can use this design to guide your own. It is preferred you do not copy it. The project evaluation will include your own innovation, design, analysis and execution of the objectives.

The instructors will answer any questions you may have during the project discussion class.

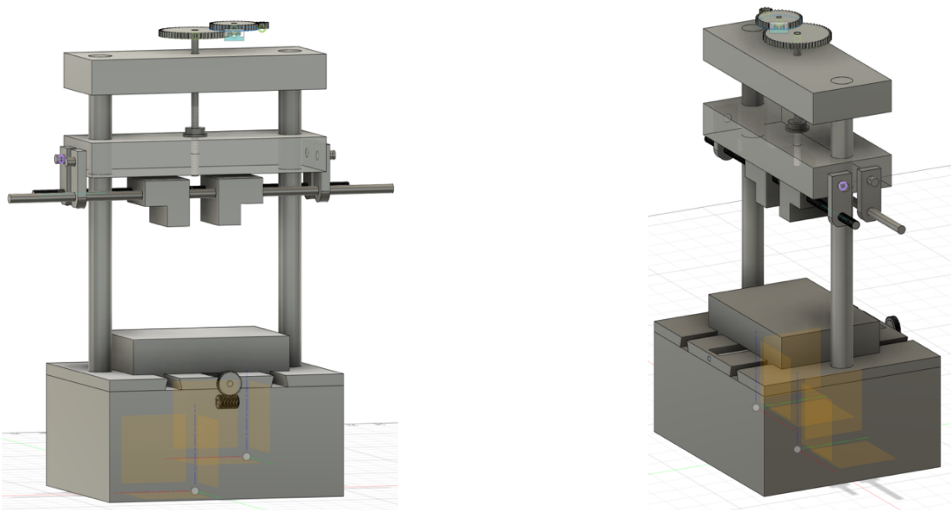


Figure 4: CAD model of our simple design satisfying all the objecives set for the project. At the bottom is a linear slide using a dovetail mechanism for linear motion, mounted on a fixed base. In the middle, there is a moving platform (aka crosshead) that has a grip mounted on an alignment rod and driven by a leadscrew. At the top is a fixed platform with a gearbox connected to a leadscrew, which moves the middle moving platform.

Notes:

1. You are not allowed to use 3D printing for fabricating the platforms and the base of the setup. Use stock material provided in the lab.
2. Linear drive mechanism (Leadscrew-Nut) as well as torque conversion mechanism (gearbox or belt drive) should be preferably made ~~and not bought~~.
3. Show your innovation and novelty in the design of ~~these three~~the mechanical components, keeping in mind that the goal is to load the specimen in tension until failure to generate a stress-strain curve.