AC 2012-3869: UNDERGRADUATE DESIGN AND MODIFICATION OF A TENSILE TESTING FIXTURE FOR BIOMATERIALS

Dr. Barry Dupen, Indiana University-Purdue University, Fort Wayne

Barry Dupen is an Associate Professor of mechanical engineering technology at Indiana University-Purdue University, Fort Wayne (IPFW). He has nine years' experience as a metallurgist, materials engineer, and materials laboratory manager in the automotive industry. His primary interests lie in materials engineering, mechanics, and engineering technology education. He is also an experienced contra dance caller.

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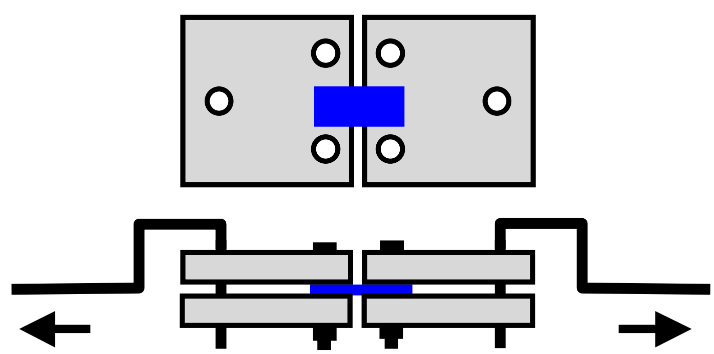
Abstract

In the freshman materials class of a Mechanical Engineering Technology program, students run tensile tests on a 270 kN universal test machine using standard metal specimens having a cross-sectional area of 130 mm^2. A Biology professor studying the development of crabs asked the MET program for help with measuring mechanical properties of crab shells. This material is a natural, porous composite. Very small test specimens with a cross-sectional area of 5 mm^2 are cut from the crab shells because larger specimens have too much curvature. With expected loads below 75 N, the 270,000 N universal testing machine was not suitable. Instead, a 250 N tabletop tensile tester was purchased. This tester pulls specimens 80 mm long, so it required modification to test crab shell material. The MET students were asked to design clamps to hold the crab shell securely without crushing it, at a predetermined gauge length. In an upcoming semester, a new class of students will customize the software to produce meaningful results. This project was good training for future engineers because it helped students learn to work on an interdisciplinary problem for an external customer (the Biology professor) where the inputs were not all known at the beginning.

Introduction

In the middle of the Fall 2011 semester, biology professor Dr. Jennifer Taylor at Indiana University – Purdue University Fort Wayne (IPFW) requested help designing and building a test fixture for measuring mechanical properties of crab shells. Specifically, the desired properties include yield strength, tensile strength, and Young's modulus.



These shells are brittle, porous, curved, small, and damp. At a previous institution, Dr. Taylor had cut shell test specimens measuring 10 mm long, 5 mm wide, and 1 to 2 mm thick.[1] She then applied cyanoacrylate adhesive to bond a specimen (blue rectangle at right) to 19 mm square aluminum plates (gray squares with three holes). The plates were sandwiched to make a clamp, tightened with a pair of small screws and nuts. Hooks passing through holes were connected to the tensile testing machine.

The weak, brittle crab shells would occasionally break while they were being clamped, perhaps because they could not support the cantilevered weight of one clamp while the second clamp was being tightened. The screw-and-nut assembly required a three-handed operation: one hand to hold the fixture, a second to hold a screwdriver to the screwhead, and a third to operate a wrench on the nut. Both screws had to be tightened in parallel in order to provide uniform clamp loading on the shell.

IPFW has two universal testing machines: a 1.1 MN Tinius Olsen with computer control and a 270 kN Tinius Olsen with manual control. In her previous tests, Dr. Taylor used a 500 N load cell and never exceeded 75 N of applied load. Clearly, a 270 kN tensile testing machine is not appropriate for samples this weak and small.

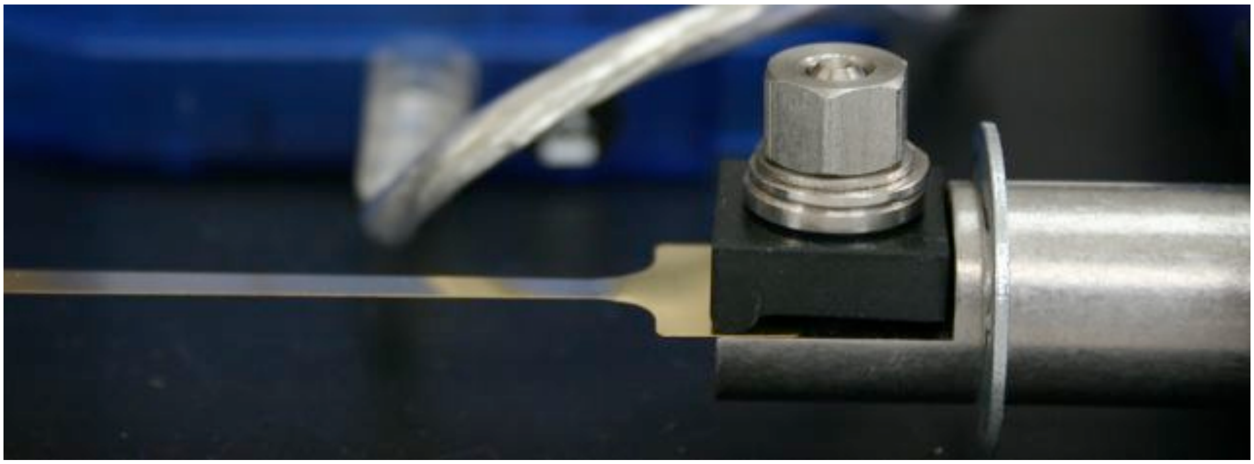
An internet search showed a promising alternative from PASCO[2] which costs about $1000 including software compatible with Apple Macintosh or Microsoft Windows operating systems. The black aluminum base plate of the tester measures 14.4 cm by 21.4 cm, smaller than a sheet of office paper. The apparatus was designed to test polymer and metal foil specimens with an 80 mm gauge length, and does not have automatic strain rate control. The test specimen is at the lower left, parallel to the bottom edge. Clamps are beneath the two hex nuts visible at the lower left and lower center. Strain is applied by manually rotating the black knob at the lower right; strain is measured with a rotary motion sensor (blue box, upper right) which is connected by a belt (barely visible) to the black knob. Force is measured with a 50 N linear force sensor (blue box, top) which touches a pivoting lever arm (black bar, left). By mechanical advantage, the pivoting arm reduces the load on the 50 N force sensor by a factor of 5, so the load capacity of the tester is 250 N.

The Mechanical Engineering Technology program purchased a tester and software, then the freshman Materials & Processes class was invited to develop designs for an improved clamp, to be manufactured by the University's machine shop. Students were permitted to work either in teams or individually, earning extra credit points. Students were asked to follow these design guidelines:

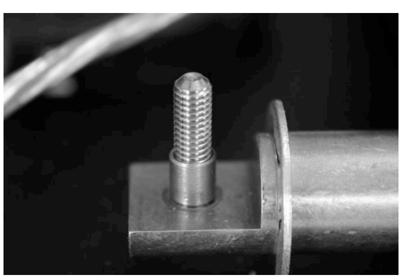
- Clamp force should be easy to apply (one-handed operation is desirable; fewer screws are desirable).
- Fixture should automatically set the gauge length at 2 mm.
- Clamp must not crush or damage the specimen.
- Fixture must fit the tensile testing machine with a minimum of modification to the apparatus.
- In order to prevent bending failure of the test specimen, the fixture should be installed onto the tensile tester before the sample is installed in the clamps.
- Drawings or sketches should be accompanied by a written description.

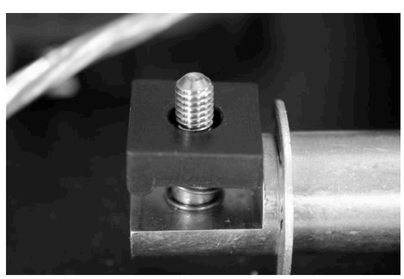
At IPFW, freshman Mechanical Engineering Technology and Industrial Engineering Technology students take a 3-credit Materials & Processes class, which includes a laboratory component. Most of these students have taken an introductory 2-D CAD class, but at this point in the curriculum, none have taken Statics, Strength of Materials, or Machine Design. Students had access to the PASCO machine during two class periods and during office hours.

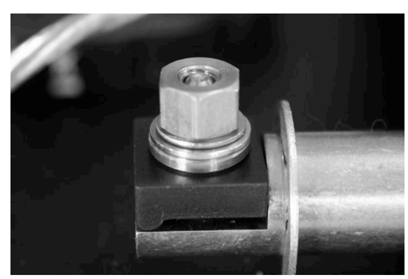
The PASCO clamps hold a strip of polymer sheet or metal foil; 76 μm thick brass is shown in the photo.



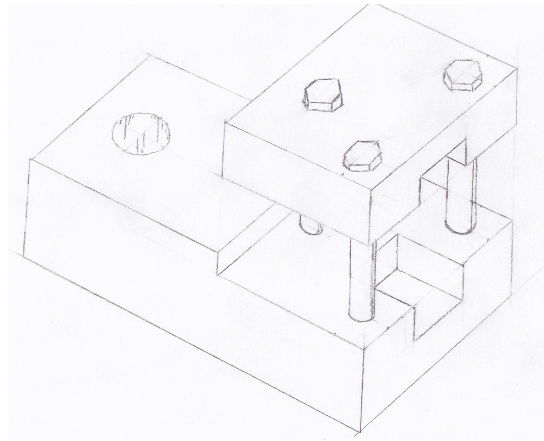
The black anodized aluminum grip has a rounded edge along the left edge, which clamps the brass strip against the stainless steel puller. There is a single-point contact at the right, and the stud passes through the center hole of the grip. Spherical washers ensure good clamping by the nut regardless of the specimen thickness.





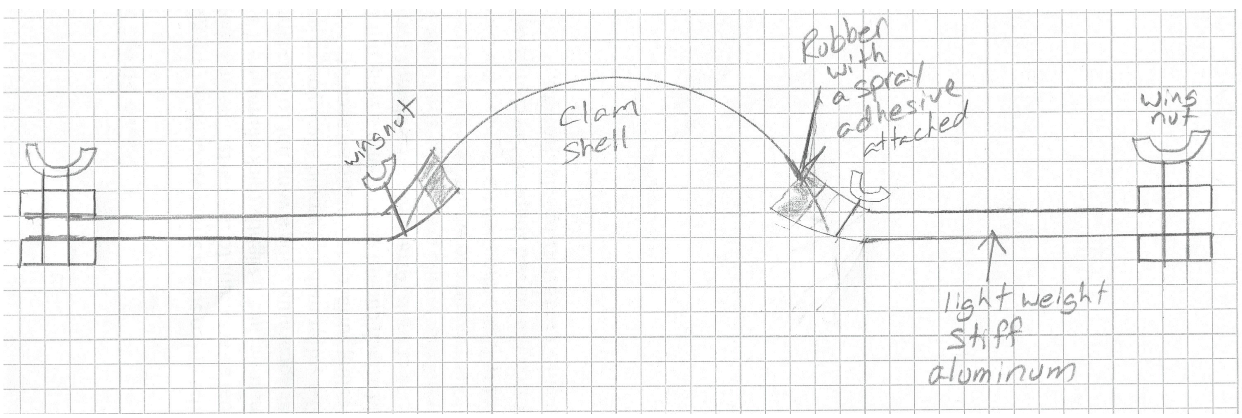


Student Designs



Student #1 supplied an assembly drawing but omitted any description of the design. This clamp uses three screws to hold the specimen. The drawing includes no dimensions; the total depth of the two slots must be less than the thickness of the test specimen.

Student #2 designed a clamp for a shell with considerable curvature – perhaps because the student confused “crab shell” with “clam shell” and assumed more curvature than is appropriate for the sample size. A single wing nut holds the shell in each clamp jaw, eliminating the need for tools (but requiring small fingers?) The entire fixture is gripped by the existing clamps, however wing nuts replace the existing hex nuts.

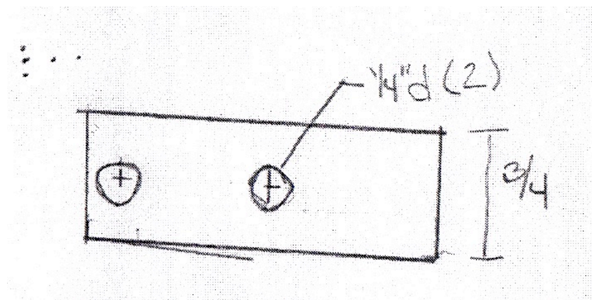


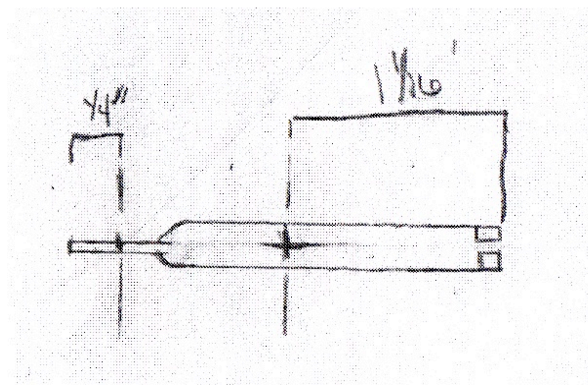
The student describes this design as follows:

> I am trying to improve the PASCO stress strain apparatus. I am going to concentrate on the actual attachment to the parts. The first thing I would do is use a lightweight stiff material like a slightly thick aluminum. I would attach the aluminum to the current apparatus using a wing nut to alleviate the use of tools to test the clam shell. The stiffer material would allow you to keep an equal distance between the testing surfaces to ensure an accurate reading. At the end of the aluminum I would attach curved clamps with a wing nut to allow for easy tightening without the use of tools. Attached to the clamps I would use a soft, lightweight rubber material that would grab on the shell without breaking it. The last important addition that I would use would be a spray adhesive on the rubber material to allow you not to clamp the shell too tight so the shell does not break during clamping. I think that the curved shape of the clamps will help the device use the shell's shape against it to test its tensile strength.

This student specified rubber grips to protect the test specimen from crushing, not realizing that the rubber will deform during testing and will increase the apparent strain readings. The design of the grips is not particularly clear.

Student #3 designed a single-screw clamp, eliminating the need to balance the clamping load between multiple screws. Pencil sketches were provided of top and side views, along with some dimensions in inches. The student describes the design as follows:



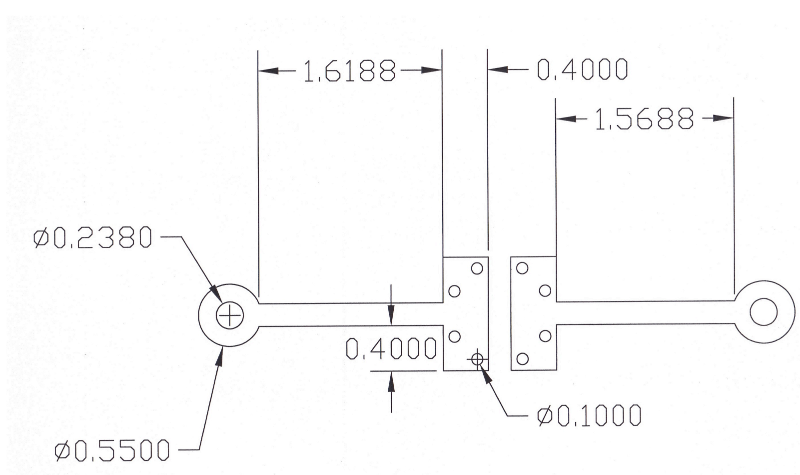


> I have determined that using a clamp that is very similar to a tweezer would work for testing a small specimen such as a crab shell. With some type of rubber coating on the tip to ensure a firm, non-slip grip, with minimal room for cracking.
>
> The dimensions of the design for one arm are as follows:
>
> The total distance of the arm will measure 2 1/8 inch long and 3/4 inch wide. With two 1/4 inch holes with the center of the holes located 1 1/16 inch from the end to allow for the screw needed for adjustment, and 1/8 inch from the end to attach the Pasco testing machine. Repeat for second arm.
>
> The clamp will attach to the PASCO tester in the same manner as the supplied specimens that come with the machine. This style will allow the user to adjust the pressure applied in holding the specimen by simply turning a screw.
>
> The user would first insert the specimen into one side of the clamp and adjust the grip of the clamp by turning the screw in a clockwise rotation. The user will repeat to attach the opposite clamp.

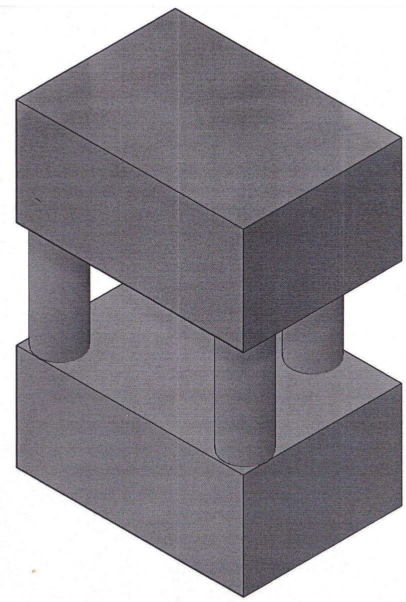
This design also uses rubber grips to prevent crushing.

Student #4 provided two CAD drawings: a plan view with many dimensions in inches and a 3-D rendering of the grip. The student explains the design as follows:

> Here is a quick explanation on the part that I have created to allow the biology department to tensile test their materials on this new machine. The first interesting thing about my piece is that the two sides are not symmetrical. I did this to keep the overall length of the piece at 4.7" just like the calibration bar included with the machine. In doing so one also should take into account that one side of the machine has an obstruction that goes



about an inch and a half out. For that side it seems that the best side of the piece is the longer of the two. After you have figured this part out one can notice the 4 holes on each end of the two pieces. These holes are to be threaded with a bolt of the department's choice. I chose to do it this way rather than using a clips because now you can control the downward force and reduce any slippage that may occur. As you can see from the second drawing there is to be a second block on top that is to screw into the block on the bottom. This design should be quite easy to use and should allow the user to have some control over the piece as needed.



Although this design uses four clamping screws per grip, the student clearly paid attention to how the clamp will fit into the test apparatus. The student measured the space available and designed the clamp to fit. Two dimensional omissions are the thickness of the material and the width of the "neck" regions. The overall length is about 16 mm too long.

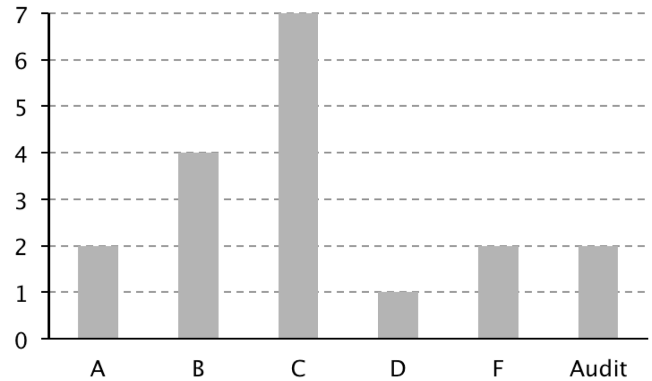
Design Comparison and Evaluation

This table shows the benefits and drawbacks of the various designs.

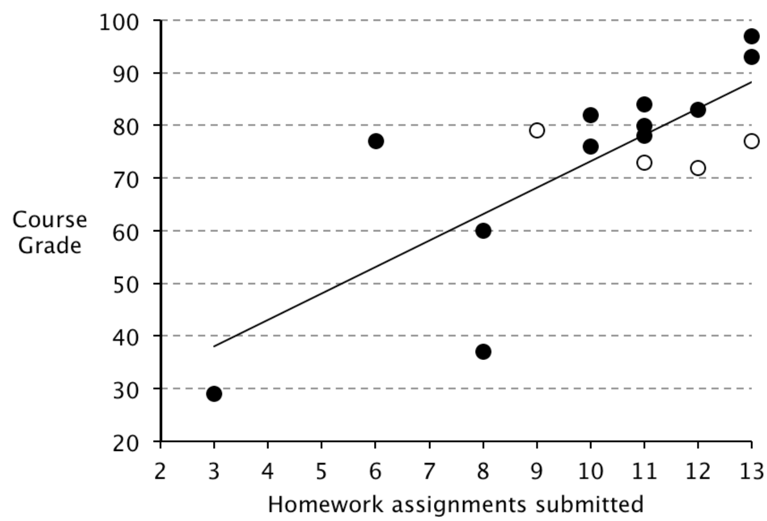
	Old clamp design	Student design #1	Student design #2	Student design #3	Student design #4
Number of screws to clamp	2	3	1	1	4
Dimensions provided on drawing	–	None	None	Some	Most
Automatically sets gauge length	No	No	No	No	No
Specimen installed after fixture is installed in the tester, to prevent specimen bending fracture	No	Unclear	Yes	Yes	Yes
Dimensions of test apparatus considered	–	No	No	No	Yes
Method to prevent crushing	No	No	Yes	Yes	No
Written description of the design	–	No	Yes	Yes	Yes

Student #1 did not submit written documentation, and increased the number of screws per clamp. Students #2 and #3 improved the existing design by reducing the number of screws on each grip from 2 to 1, and included rubber grips to prevent crushing of the brittle test specimens. Student #4 examined the test apparatus a second time to measure the location of existing components, in order to avoid interference between these components and the fixture. Student #4 also had the best dimensioning (although the fixture is 16 mm too long). None of the designs automatically sets the gauge length at a fixed dimension.

Participation and Design Quality



This project was introduced in the middle of the semester, too late to make it a required assignment, so it was offered as an extra-credit assignment. Points would be awarded based on the quality and completeness of each design. Unfortunately, this policy reduced the quality of the clamp design submissions. By the end of the course, the grade distribution was somewhat bell-shaped, with the largest number of students earning a C. Four students stopped submitting work during the semester; two of them switched to Audit status before the deadline, while the other two earned an F for the course. These four students did not submit the extra-credit assignment, probably because it would not have helped their grades. The student who earned a D was on the ragged edge of earning an F, and likewise did not submit a design. The students who earned high grades did not need the extra-credit points, so they did not participate. As as consequence, the only submissions were from C students.



This graph shows the course grades as a function of the number of homework assignments submitted. Data from 16 previous semesters shows a weak to moderate correlation between theses two variables, with a coefficient of determination r^2 of 0.30 in the worst case to 0.85 in the best case, for classes of 10 to 18 students. In this semester, the four students who participated in the clamp design project are represented by hollow circles, in the range of 70 to 80%, or a C grade. Of the students who turned in all 13 homework assignments, the lowest-performing student was the only one to seek extra credit; the same is true for the students who turned 12 assignments, and those who turned in 11. In retrospect, it would have been better to include the design project as a required assignment with a specific number of points, rather than as an extra-credit assignment.

Assessment and Lessons Learned

The plan of this project was to run a design completion, select the best design ideas, have one or two of the best designs made in the university's machine shop, then test some crab shells before the end of the semester. Since the project started just past the middle of the semester, there was not enough time to accomplish all three tasks, and none of the submitted designs met the full set of design criteria. If the project had been introduced early in the semester as a required part of the curriculum, the students earning an A or B for the course would have submitted designs which would have been more likely to meet the criteria.

Freshman design projects are necessarily a gamble; students are asked to design a structure or machine before taking any mechanical design courses, so the results are often strong in concept but weak in technical soundness. Clearly, juniors or seniors would have developed better designs. However, by exposing freshmen to a design problem early in their academic careers, they will better appreciate the need for Statics, Strength of Materials, Machine Design, and other core design courses.

Further Work

In the coming semester, the best features of the student designs will be combined to manufacture a fixture which meets all design guidelines, and materials testing will begin.

[1] Jennifer R. A. Taylor, Jack Hebrank, and William M. Kier, "Mechanical properties of the rigid and hydrostatic skeletons of molting blue crabs, *Callinectes sapidus* Rathbun," The Journal of Experimental Biology 210, 2007, p. 4272-4278.
[2] PASCO AP-8214 Stress/Strain Apparatus with PASPORT sensors, Powerlink interface, and DataStudio software, available from PASCO Scientific, 10101 Foothills Blvd., Roseville, CA 95747, or www.pasco.com.