AC 1999-141: A Four-Point Bend Test Experiment for Use in the Classroom, and Procedures for Evaluating Results

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Abstract

Texas A&M University is a member of the Foundation Coalition, which is funded by the National Science Foundation. As part of the development of the sophomore engineering science courses, several in-class laboratory demonstrations have been developed. One of these is a four-point bend test. The students are able to make load-deflection measurements in the classroom, and determine the modulus of elasticity for different materials. This paper will describe the setup, procedure, and give examples of how different evaluation methods correlate.

Introduction

During the development of the engineering science core courses at Texas A&M University, the faculty decided that it would be beneficial for the students to have some in-class laboratory activities. Under the auspices of the Foundation Coalition,[1] a program of the National Science Foundation, several activities have been developed. The students taking ENGR 213, a properties of materials course, perform a tensile test, a thermal conductivity experiment,[2] and determine the behavior of several electrical components in addition to the 4-point beam bending experiment for determining the modulus of elasticity.[3]

The core engineering science courses developed are listed in Table 1.[4,5] The connecting thread through these classes is the application of conservation principles.[6] The experiments were developed for a materials course (ENGR 213), which is course is taken by the majority of departments within the College of Engineering at Texas A&M.

This paper will describe the test apparatus, the procedure, and evaluate several methods for determining the modulus of elasticity.

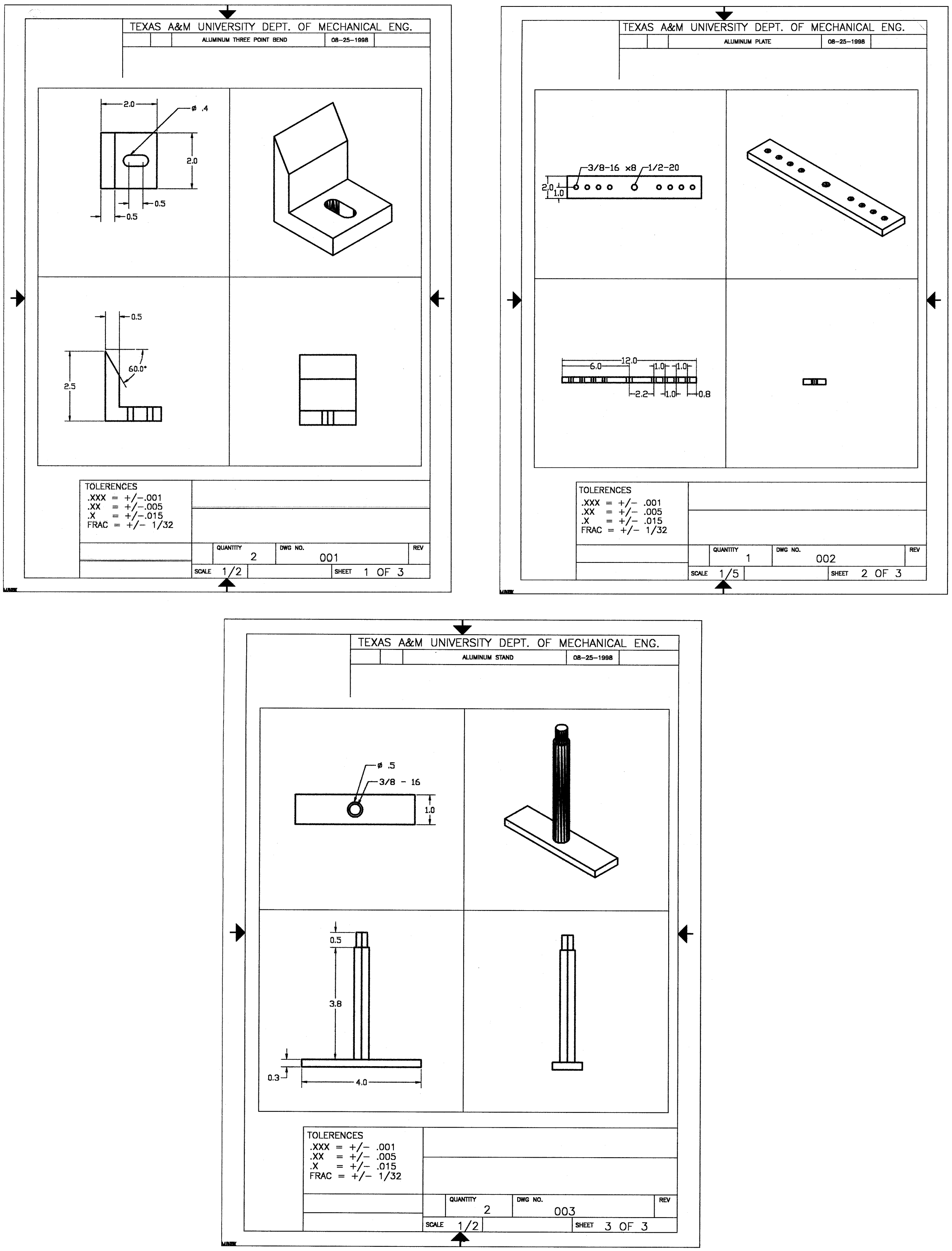

Figure 1. Drawings for the 4-point bend apparatus.

Table 1. Arrangement of courses.

Semester	Engineering Area	Texas A&M University Course Numbers
Fall	Mechanics- Statics and Dynamics	ENGR 211
	Thermodynamics- plus some fluids	ENGR 212
Spring	Materials	ENGR 213
	Continuum Mechanics	ENGR 214
	Electrical Circuits and Electronics	ENGR 215

Experimental Setup

Figure 1 gives the plans for the 4-point bend test apparatus. The dial indicator is below the beam in the test setup as shown in Figure 2. This results in a small upward force due to the spring associated with the dial indicator.

The total cost for a setup is given in Table 2.

Table 2. Equipment needed for the 4-point bend test.

Components	Estimated cost
Bend Fixture, Stainless steel	$50
Dial indicator, collet, and extension	$53
Weights	$25
Beams	Used available materials
Screws, bolts, and nuts	$5
Vernier caliper	Available in laboratory
	$133 Estimated cost per setup

A photograph of the students using the apparatus is shown in Figure 2.

Procedure

The procedure for determining the modulus of elasticity is the following. Students measure the dimensions of the beams and the test apparatus. As shown in Figure 2, the students increase the mass of the weights on the beam and correspondingly measure the deflection of the dial indicator. The results for a graphite/epoxy and a 304 stainless steel are shown in Tables 3 and 4. The dimensions for the graphite/epoxy and the stainless steel are given in Table 5.

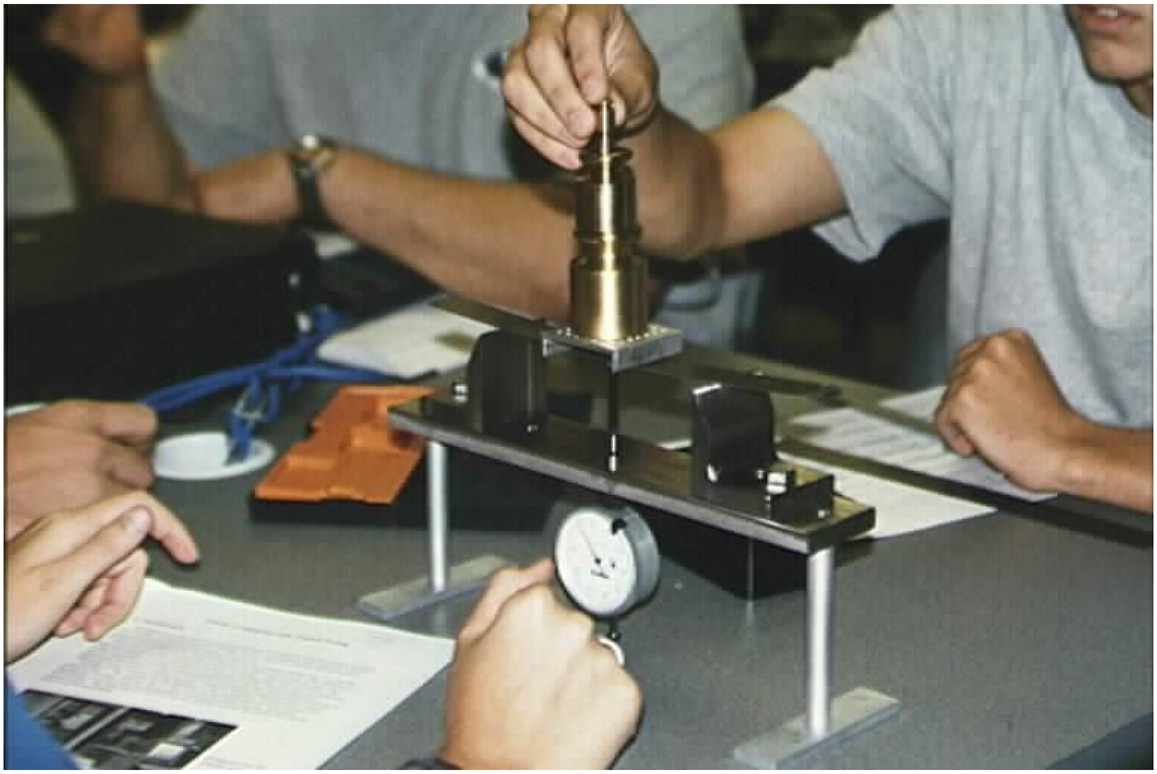

Figure 2. Students making a measurement using the 4-point beam bend apparatus.

Table 3. Data for the Graphite/Epoxy beam.

Beam Material	Load (N)	Net Deflection of Beam (m)	Young's Modulus taking k = 0 (GPa)	Young's Modulus taking k=78.0947 (GPa), Eq. 1	Young's Modulus taking K=78.0947 (GPa) Eq. 2
Graphite Epoxy	1 * 9.81	0.0003832	234.81	217.30	233.9666
	1.2 * 9.81	0.0005112	211.22	197.88	210.37
	1.5 * 9.81	0.0006886	196.00	185.89	195.16
	1.7 * 9.81	0.0008362	182.93	174.45	182.09
	2.0 * 9.81	0.0009692	185.68	178.25	184.84
	2.2 * 9.81	0.001092	181.27	174.59	180.43

Table 4. Data for the UNS 30400 beam.

Beam Material	Load (N)	Net Deflection of Beam (m)	Young's Modulus taking k = 0 (GPa)	Young's Modulus taking k =78.09 (GPa), Eq. 1	Young's Modulus taking K=78.0947 (GPa) Eq. 2
UNS 30400 Stainless Steel	0.5 * 9.81	0.0014490	207.41	172.35	201.79
	0.6* 9.81	0.0017618	204.69	174.86	199.08
	0.7* 9.81	0.0020778	202.50	176.35	196.88
	0.8 * 9.81	0.0023988	200.46	177.06	194.84
	0.9 * 9.81	0.0027282	198.29	177.03	192.67

Table 5. Dimensions for the test specimens.

Dimensions (m)	Graphite/Epoxy
L	0.142
w- width	0.0257
t- thickness	0.00135
	UNS 30400
L	0.142
w- width	0.0279
t- thickness	.00071

Analysis

The loading points and the dimensions are shown in Figure 3. For the tests reported in this paper, a=b, and L=3a.

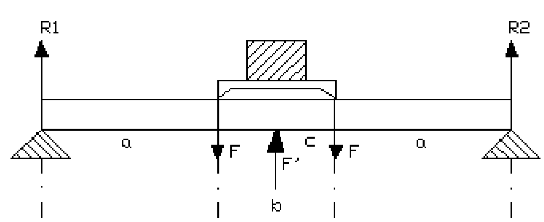

Figure 3. Schematic for the 4-point beam setup.

The expression for the modulus of elasticity has been derived using a double integration technique that allows for a preload on the specimen due to the spring in the dial indicator. Using this method of double integration the following equation was derived.

$$E = \frac{F * C_1}{I * \delta} + \frac{F_1 * C_2}{I * \delta} \qquad \text{Equation 1}$$

Where, F= P/2 (P is the load applied to the beam.)
F_1 is force exerted by the dial gauge on the beam
F_1 = k*y, where y is total the deflection of the dial gauge, and k is the spring constant for the dial indicator (k = 78N/m)
$C_1 = -46b^3/48$ and $C_2 = 27b^3/48$ are constants and for the geometry used in this setup C_1 = -0.0001015448, and C_2 = 0.0000596022
I-moment of inertia = $wt^3/12$, w- width, t- thickness of the beam
$I = 5.535 \times 10^{-12}$ m^4 (Graphite-Epoxy), 8.286×10^{-13} m^4 (UNS 30400)
δ- net displacement of the beam

Using the principle of superposition, the following expression can be derived.

$$E = \frac{F(3aL^2 - 4a^3)}{48I\delta} - \frac{kL^3}{48I} \qquad \text{Equation 2}$$

Where, $L=2a+b$, a and b are defined in Figure 3, a=b, L=3a
Other terms defined above

Equation 2 ignores any preload associated with the dial indicator.

Another way to look at this problem is to use the ASTM Standard Test Method, D 790-96a, <u>Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials</u>. Two relationships are included in the standard for a load span of ½ and 1/3 of the support span. These relationships are:

$$E_b = 0.17L^3 \frac{m}{bd^3} \qquad\qquad E_b = 0.21L^3 \frac{m}{bd^3}$$

Equation 3 for ½ the support span. Equation 4 for 1/3 the support span.

Where, L is defined earlier
b- width of beam, and d- thickness for beam
m is the slope of the load deflection curve (see Figure 4)
For SI units, b and d are in mm and m is N/mm

Equations 2, 3, and 4 ignore any upward force associated with a dial indicator. In fact equation 3 represents a 3-point bend setup, and can be ignored for this discussion. The results using Equations 1, 2, and 4 are shown in Table 3, 4, and 6. The modulus for the graphite/epoxy was taken as an average of the last three points shown in Table 3. The scatter in the initial 3 data points is associated with the difficulty of making the deflection measurements under conditions of low loads. For the stainless steel, Table 4, that is not a problem and the modulus was determined using all five of the data points. The load-deflection data is plotted in Figure 4. The slope for the graphite/epoxy using the last three data points is 19,600 N/m, while the slope for the UNS 30400 is 3,070 N/m.

The columns listed in Tables 3 and 4, which have k = 0, represent the case for no contribution from the dial indicator, where as the two columns to the right represent the calculation of the modulus using Equations 1 and 2 respectively. A handbook value for the UNS30400 is 193 Gpa.[7] There is no corresponding handbook value for the graphite/epoxy because the properties and volume fraction of the individual components are unknown.

It is possible to ignore the correction, and if one does, a question that could be asked of the students is "How does ignoring the upward force affect the modulus that was determined?" Of course, the calculated modulus would appear to be higher or the material would appear to be stiffer when the force associated with the spring is ignored. The data shown in Table 6 supports this conclusion. For both Equations 2 and 4, the calculated modulus is higher when the opposing force from the dial indicator is ignored.

Table 6. Calculated moduli of elasticity using different equations.

Material	Modulus GPA		
	Equation 1	Equation 2	Equation 4
Graphite/Epoxy	175	182	184
UNS30400	176	194	183

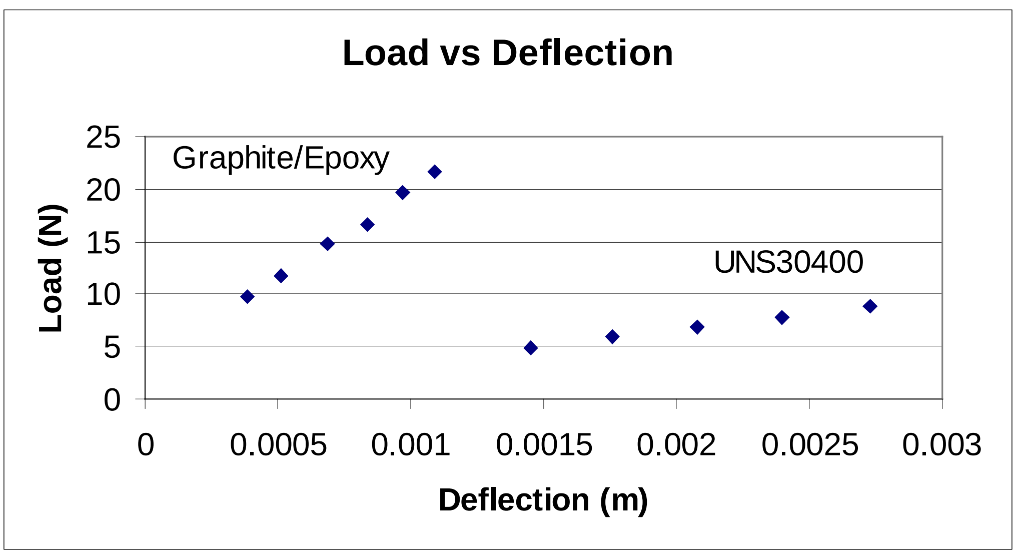

Figure 4. Load deflection data for graphite/epoxy and stainless steel.

Conclusions

A 4-point beam bending experiment was developed for use in a classroom setting. Students work in teams, and are able to measure the load deflection characteristics of a beam and calculate the modulus of elasticity for different materials.

Acknowledgement

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Bibliography

[1] Malave, C.,"Teaming in the Integrated Curriculum of the Foundation Coalition at Texas A&M," ASEE National Conference, Washington, D.C., June 1996.
[2] Griffin, R. B., Ragupathi, P., Johnson, E., “Development of a Thermal Conductivity Experiment for Use in Class,” ASEE, Seattle, WA, 1998.
[3] Griffin, R. B., Cornwell, L. R., Yapura, C., Krishnan, S., and Hallford, J., "Use of a Four-Point Bend Apparatus to Determine the Modulus of Elasticity," National Educators Workshop Update 98, Brookhaven, NY, 1-4 November, 1998.
[4] Griffin, R. B., Everett, L. J., Keating, P., Lagoudas, D., Tebeaux, E., Parker, D., Bassichis, W. and Barrow, D., “Planning the Texas A&M University College of Engineering Sophomore Year Integrated Curriculum,” Fourth World Conference on Engineering Education, Oct. 95, St Paul, MN, vol. 1 pp. 228-232.
[5] Griffin, R. B., Everett, L., and Lagoudas, D., “Development of a Sophomore Year Engineering Program at Texas A&M University,” FIE, Pittsburgh, PA, Nov. 1997.
[6] Glover, C., “Conservation Principles and the Structure of Engineering,” McGraw-Hill, New York, NY, 1996.
[7] ASM Metals Reference Book, 2nd ed. ASM, Metal Park, OH, 1983

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