AER 304: Beam Bending

University of Toronto Institute for Aerospace Studies

1. Purpose

The goal of this lab is to demonstrate the behaviour of some standard configurations of beams in bending. Three beams will be tested. First, an aluminum I-beam will be tested in both three-point and four-point bending, in order to illustrate the differences in the strain distribution in the web of the beam. Second, a sandwich beam composed of a polymer foam core and a composite face sheet will be tested to destruction to provide insight into complex structures subject to several competing failure mechanisms. Third, the beams designed by the lab groups and fabricated using a 3-D printer will be tested to destruction.

2. Safety Considerations

This is an active research laboratory. Several fundamental safety precautions must be followed:

- There are many heavy objects that may accidentally be dropped. Reasonably sturdy closed footwear is a necessity. No flip-flops or open-toed shoes.
- Loose clothing and unconstrained long hair are hazardous. The servo-hydraulic MTS load frame is capable of displacement rates up to 100 m/s. If something loose gets caught in the machine, very serious injuries may ensue.
- Safety goggles must be worn while experiments are in progress.
- No mobile telephones are permitted in the laboratory: if you are looking at your phone you are not paying attention to the equipment.

3. Apparatus

- MTS 100 kN servo-hydraulic load frame equipped with bending rig
- National Instruments LabView data acquisition system
- Bamuer Electric laser distance sensor
- VIC-Snap image acquisition hardware and software
- Ncorr digital image correlation software

4. Experimental Setup

A set of three beams made of metal, composite and polymer will be prepared for each laboratory session. The metal beam will be an aluminum 6061 I-beam with nominal dimensions height 3”, width 2.51” and thickness 0.35”. Note that these nominal dimensions are Imperial. On one side of the web of this beam, near but not at the centre of the beam, a black and white speckle pattern will be applied to the top half of the beam. On the opposite side of the beam, a set of strain gauges (TML FLA 5-11 gauge characteristics: 120 Ω, gauge factor 2.13) will be applied. The sandwich beam will be composed of several sheets of woven glass fibre / epoxy composite and a Rohacell polymer foam core. The exact specifications and dimensions of the foam core and the face sheets will vary from laboratory group to laboratory group. The 3-D printed polymer beam will be as designed by the lab groups.

The 100 kN MTS servo-hydraulic testing frame will be used to apply load to the beams. The load frame will be equipped with one compression platen on which the support arm of the bending test rig will sit. The loading arm of the bending rig will be affixed to the opposite arm of the MTS. The experiments will be controlled through the piston displacement of the load frame.

The experimental data will be collected through three different methods. The strain gauges on the reverse side of the aluminum beam will collect data on the axial and shear strain near the centre of the beam. Digital images of the speckle pattern will be collected for use with digital image correlation. A laser displacement gauge will measure the displacement of the bottom surface of the beams. Note that for the composite and polymer beams, only the laser gauge will be present.

5. Experimental Procedure

5.1. Aluminum I-Beam: The first specimen to be tested will be the aluminum I-beam. The beam will be supported by two rollers 400 mm apart. Measure the various cross-sectional dimensions of the beam following the test. The displacement of the cross-head will be limited to ensure that the beam does not suffer any inelastic deformation. The first testing configuration will be four-point bending. Load will be applied by a pair of rollers separated by 120 mm, centred on the mid-point of the beam. The beam will be loaded to approximately 20% of its predicted yield load, at very low displacement rate, and then unloaded. The test configuration will then be changed to a three-point bend configuration, with the loading roller at the mid-point of the beam. The I-beam will be loaded a second time, again to 20% of the expected yield load, at very low strain rate. The goal of these two tests is to demonstrate the differences in strain state (and hence stress state) between three-point and four-point bending.

5.2. Composite Sandwich Beam: The next test specimen will be a sandwich beam composed of woven glass or carbon fibre composite face sheets and a polymer foam core. Loading will again be by three-point bending and will proceed to destruction. The goal of this experiment is to see how a composite system with multiple failure mechanisms behaves in practice. Again, measure the sandwich beam and the configuration of the bending rig (specifically the distance between the support rollers) carefully.

5.3. 3D Printed Beam: The final beam to be tested will be the 3D printed beam designed by the laboratory groups and fabricated in the MIE machine shop fused filament fabrication 3D printer. This experiment will illustrate some of the possible failure mechanisms that may be found in beams of arbitrary shape and will provide some entertainment for students, TAs and the professor.

6. Data Acquisition

There will be four primary sources of experimental data. First, the MTS will provide force data from the load cell. Second, digital images of a speckle field will be captured using VIC-Snap and a digital camera. Third, a Baumer Electric laser distance sensor will measure the mid-point deflection of the beams. Finally, four strain gauges will be adhered to the aluminum I-beam (locations shown in figure 1). The data will be collected using a custom LabView virtual instrument developed for this set of experiments. Again, Ncorr will be used to analyse the digital images and calculate strain fields. For a reminder of the steps to get Ncorr running, see the lab manual from the tensile testing lab.

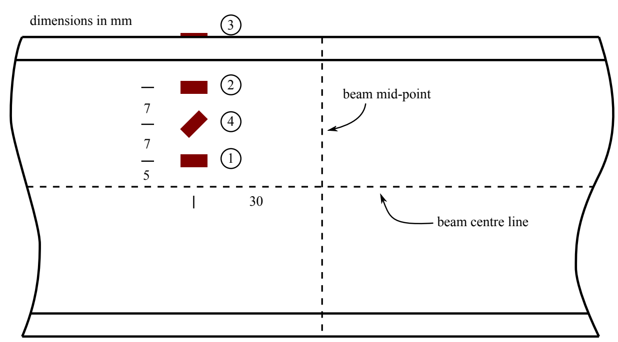

Figure 1: The locations of the strain gauges adhered to the aluminum I-beam.

7. Beam Bending Behaviour

The goal of this laboratory is to observe beams in static three-point and four-point bending, and compare the observations to theoretical predictions. Amongst the behaviours that should be observed are:

- the spatial variation in strain and its consistency with theory;
- the failure characteristics associated with complex structures with competing failure mechanisms; and
- the performance of a 3D printed beam with arbitrary geometry.

7.1. Material Properties: Table 1 enumerates the relevant material properties for these experiments.

Material	Young's Modulus	Shear Modulus	Tensile Strength	Compressive Strength	Shear Strength
Aluminum 6061	72 GPa		276 MPa		
Glass fibre composite	31 GPa		490 MPa	350 GPa	
Carbon fibre composite	70 GPa		600 MPa	570 MPa	
Rohacell 51-IG foam	67 MPa	19 MPa		1.01 MPa	792 kPa

Table 1: Material properties for composite, polymer foam and aluminum used in these experiments.

8. Laboratory Report

You must keep the size of your report below 5 MB. The report is due by midnight seven days after the laboratory session.

8.1. Aluminum I-Beam: For the aluminum I-beam (material Al-6061), compare the output of the strain gauges with the results of the digital image correlation, and determine whether these measurements are consistent with each other and consistent with theoretical predictions of how strain should be distributed through a beam with this geometry. Explain what is the purpose of strain gauge 4, which is oriented at 45° to the axis of the beam.

8.2. Composite Sandwich Beam: For the sandwich beam, using the equations on sandwich beams provided in AER 373, discuss the likely failure mechanism of the beam according to theory and compare to your observations. Compare the strength and stiffness of the beam to analytical predictions.

8.3. 3D Printed Beam: Discuss the process you employed to design your beam: how did you choose the geometry? Which failure mechanisms did you consider? How did you generate your predictions for strength and stiffness? How did the performance of your beam compare to your predictions?