Sustainable development: Understanding How Things Break

Robert R. McCullough[1], Dr. Beth A. Todd[2], Dr. J. Brian Jordon[3]

Abstract - As our nation's and the global economy continue to expand and develop, an understanding of the potential of our planet's natural resources to support our needs is imperative for students preparing to enter the workforce. Sustainability is essential to this understanding as it focuses on a clear definition of the boundaries and limitations of those natural resources. For an engineer, it is vital to be able to effectively describe the performance and behavior of materials to better understand their potential applications, a process referred to as characterization. Understanding characterization allows for the optimization and minimization of the quantity of material used, proper selection of materials for application, and determining life span of a design.

Keywords: Sustainability, force, material engineering, characterization, hands-on activity

Background

Sustainable development is a concept and even a philosophy of human development that has arisen over the past few decades due to our increased awareness of our own impact on the ecosystem. Nowhere has this awareness become more acute than within the U.S. economy [7]. The concept of sustainability is not new, however the attempt and even the growing need to clearly formulate and implement sustainable practices into modern culture is new [10]. This change in perspective can be seen in the increasing number of the issues that are tied to the ideals and mechanisms of sustainability; existing at the very forefront of today's modern psyche. Issues like global warming, energy consumption and the global water crisis are all of growing around the globe and nowhere are they seen more clearly than in the United States [3, 12],

As one of the world's most advanced economies, the U.S. is a leader in social development, technological innovation and product manufacturing and consumption. However, this has come at the cost of being at the forefront of material consumption and waste. It has been noted that as much as 94% of the total material products being consumed are disposed of as waste within only a few months of their fabrication [7]. Also, the United States consumes over 18% of the world's energy, while only representing only 4.5% of the global population. In addition to this over 80% of this energy is being generated from non-renewable fossil fuels, such as coal, oil, and gas [2, 3].

Now as the global population and economic market continue to expand, the availability and quantity of material resources have become a serious and growing concern. Sustainability ideals confront these issues, as resources become more and more constrained; a larger number of societies are taking a "less is more" minimization mentality [13]. However, this tactic only curves the initial issues of consumption. Sustainable development takes minimization to the next level and looks to develop products that both minimize material consumption and allows for the increased production of product and services to meet growing demand. The sustainable development mentality allows economies to continue to grow and expand, all while still maintaining a mindset that is focused on curving excess material consumption [6, 7].

At its core sustainability is very simple; sustainability is maintaining the resources of the environment that allows for the continuation of society. Sustainable development is simply the creation of a method that forms a sustainable process and/or society. Sustainability is not just a supplementary concept, but it also explains how systems work on

[1] Graduate Student, University of Alabama, Department of Mechanical Engineering, The University of Alabama, Box 870276, Tuscaloosa, AL 35487-0276, rrmccullough@crimson.ua.edu
[2] Associate Professor, University of Alabama, Department of Mechanical Engineering, The University of Alabama, Box 870276, Tuscaloosa, AL 35487-0276, btodd.eng@gmail.com
[3] Assistant Professor, University of Alabama, Department of Mechanical Engineering, The University of Alabama, Box 870276, Tuscaloosa, AL 35487-0276, bjordon@eng.ua.edu

a foundational level. The core ideals of sustainability do not only affect the physical state of the humanity and ecosystem, but also the psychical state (mindset) of the people involved.

Development of a sustainable mindset can be modeled as the interaction of three major components: society, economics, and environment. All of these segments are made sustainable by carefully balancing the flow of resources. For economics it is the flow of money, maintaining the "life blood of human civilization." For society it is the development of products and services that affect humans on both a communal and individual level. For environment it is the flow of natural resources, sustaining the fundamental components that support life itself. By finding the optimum flow of each of these segments, a balance can be reached that is a sustainable state, as shown in figure 1 [6].

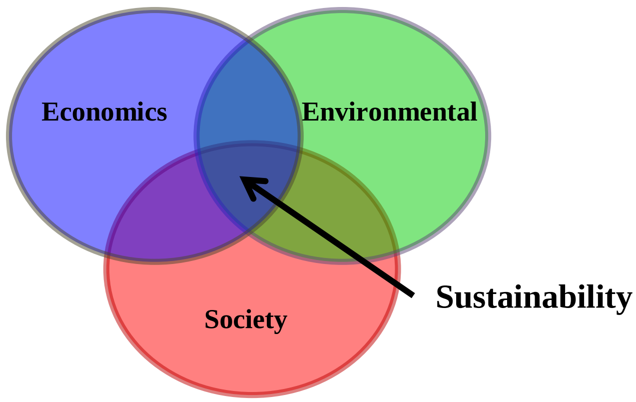

Figure 1. Triangle Chart of Sustainability Segments

Many individuals and organizations have tried to define the controlling elements of sustainability. The need to understanding both the demands of the physical and the needs of the meta-physical in sustainability is expressed in the words of former U.S. President Theodore Roosevelt in his 7th State of the Union address [9],

> "The reward of foresight for this nation is great and easily foretold. But there must be the look ahead, there must be a realization of the fact that to waste, to destroy, our natural resources, to skin and exhaust the land instead of using it so as to increase its usefulness, will result in undermining in the days of our children the very prosperity which we ought by right to hand down to them amplified and developed. "

In these words it can be seen that application of sustainability is rooted in the basic needs of society to survive. But it goes further. It expresses a deep and profound passion, a sense of honor, to support and bolster the efforts of our descendants and the continuation of our way of life. Many more concise definitions for sustainability have been developed in more recent years. The Brundtland commission a group sanctioned by the United Nations and headed by Gro Harlem Brundtland produced one of the most prevalently used definitions for sustainable development [5];

> "Sustainable development is the development that satisfies the needs of the current time period without jeopardizing the ability of future generations to satisfy their needs."

To really develop a strong grasp of the concept of sustainability, two key ideas need to be understood. It is the implementation of these ideas that really makes a sustainable mindset possible. The first concept is the understanding of the fundamental needs of both individuals and societies. This concept covers such questions as, "What are the needs of the individual or group that are the focus of study?" and "What is essential to our well-being?" The idea is rooted in our need to survive and perpetuate the society (Maintaining population, number of jobs, and access to resources). Items such as the minimum amount of food, water, financial income, and even relationships are elements that are fundamentally rooted in this idea [1].

The second idea is the concept of limitations. Questions such as, "How much pollution can the environment handle before being adversely affected?", "How much can I buy with the income available?", or "How many friendships or contacts can one develop and effectively maintain?" define the types of limits seen by society. One item to note about limits is that they can be bypassed, unlike needs [1]. However, the development of financial debt, poor quality of relationships, and even an irreversible depletion of the environment's natural resources will inevitably be the result.

While there are many ways that the underlying idea of sustainability can be expressed, it becomes very difficult to relate these ideas into concise, yet explicit illustrations. One approach would be to take a common subject such as cooking or baking and shape it around these ideas. For example, both needs and limits can be conceptualized along the lines of baking chocolate chip cookies. When making a batch of cookies, there is a minimum amount of money, time, and ingredients needed to actually make the cookies. Limits can be found in that only a finite amount of flour, sugar, butter and chocolate chips can be purchased to be use in the recipe. Also depending on the preference of the baker, the number of chips and size of the cookies can vary, increasing or reducing the number produced. For the cookies to be successfully made, the baker must have an understanding of the needed resources, available money, and demand for the cookies (do people want the cookies?).

For engineers, the control and minimization of the flow of resources is vital for maximizing sustainability. To achieve this level of sustainability, engineers need to have an understanding of how these resources work [8]. They must ask questions such as;

- How strong is the material?
- How much deformation can the material handle?
- Can it handle the environment it will be placed in?
- How easy is it to manufacture or assemble a component or system?

These are all questions that need to be asked when engineers look at new materials. This is the core focus of characterization and design. Engineers that can utilize material characterization and integrate this understanding into a sustainability mindset will have a much greater impact on the world. By thinking of these questions and then identifying the material best suited for the application, engineers can create designs that have improved longevity, environmental compatibility, and enhanced performance [4]. All of these efforts focused on satisfying the needs of society, economy, and environment that are so central to sustainability.

Module Analysis

The core idea behind this module is more centered on what sustainability is as a whole, why is it important to us as humans, rather than what it means for a specific issue. The focus is to explain the idea of sustainability in such a way that it brings to light the impact that it has on every aspect of life. All this, while still isolating and elaborating on a specific and clearly defined applications. The emphasis of the author in this paper is to develop a learning scheme that targets K-12 science classrooms to help establish a foundational understanding of the core concepts behind sustainability. The plan is to give the teachers both a comprehensive and flexible lesson plan that combines both intellectual concepts and long established engineering axioms to communicate the core ideals and applications of sustainability.

As of the publication of this paper, an assessment of the curriculum has not been performed. If time permits this work will be presents to a set of 8th grade science classrooms under the sponsorship of The University of Alabama GK12 Fellowship program. In order to properly assess the impact and effectiveness, a multistage approach will be taken. The first step will be a quiz given upon completion of the module. The quiz will consist of 4-5 short written response questions testing the student on their absorption of core definitions and concepts presented in the module.

Second, an analysis of the overall success of the activity will be based on the percentage of successful projects (incomplete beams and premature failures), length of time till completion by each team, and overall class participation in analyzing results. Optimally, as this curriculum should be introduced as a preliminary activity to such topics as ecology, economics, and physics, the class should be periodically challenged to identify and apply the idea of sustainability during the study of each of these areas. In this phase questions should integrated in the quizzes and tests proctored that allow for a quantification of the overall long term comprehension of the material and transition of this knowledge to practical lines of thought.

Conclusion

In conclusion, after the administration of this module in a K-12 science classroom, the module should act as solid augmentation tool for the existing curriculum. As designed this curriculum will give students a better understanding of the definition and application of sustainability, as well as teach them on how engineers use many of the tools and principals of mechanical engineering to implement sustainability into their designs. This new knowledge will help to prepare these students to tackle real world issues in science, engineering and mathematics in a dynamic and forward thinking way in both their everyday lives and in career fields based in science, mathematics and engineering.

Lesson Plan

As the concept of material characterization is rather complex; before beginning the activity it is necessary to introduce the students to the idea of sustainability, mechanical testing techniques, and final failure in materials. However, it is likely going to be necessary to reintroduce other topics first so that the students are thinking correctly about the working principles that go into testing materials, such as available resources, force and deformation.

1) Sustainability: Maintaining a balance between inputs and outputs
    a) Ask about class's knowledge of global warming (CO2 Emissions) and family budgets
    b) Explain how reducing CO2 emissions improves human health and maintains environment (Stable temperatures, ice caps, etc.)
    c) Talk about how for a budget to work, one must understand….
        i) What is needed? (Food, Electricity, Gas, Recreation, etc.)
        ii) Where are the limits?
            (1) How much money do I have?
            (2) Which item is more important (Food>Gas>Recreation)
            (3) How much can I buy of each?
    d) Sustainability effects all areas
        i) Home
            (1) Ex: Family Budgets – Purchasing what is needed to live with the money that is available
        ii) Business
            (1) Ex: Supply and Demand – Producing enough to meet demand and maintain company
        iii) Natural Environment
            (1) Ex: Circle of life – Populations vary with available food supply
    e) Engineers
        i) Deal with sustainability everyday
        ii) Need to understand the effect of….
            (1) Using natural resources
            (2) Power Generation (Nuclear, Coal, Natural Gas, etc.)
            (3) Abilities of materials being used (Strength, Energy Produced,
2) Materials by source
    a) Mining
        i) Resources contained under the earth's surface.
        ii) Metals (Aluminum, Gold, Iron, Lithium, etc.)
        iii) Minerals (Salts, Granite, Limestone, Silicon, etc.)
        iv) Fossil Fuels (Coal, Diesel, Gasoline, Natural Gas, etc.)
        v) Most are non-renewable
    b) Farming
        i) Resources originating on the earth are surface and cultivated by humans.
        ii) Food (Beef, Corn, Sugar, Wheat, etc.)
        iii) Fuels (Alcohol, Bio-Diesel, etc.)
        iv) Renewable form of resources
    c) Natural Environment
        i) Resources originating on the earth are surface and collected by humans.
        ii) Wood
        iii) Clean air
        iv) Food (Fishing, Hunting, etc.)
        v) Renewable form of resources

3) Force
    a) Interaction between two objects that causes:
        i) Pushing
        ii) Pulling
        iii) Bending
    b) Cause objects to move
    c) Newton's Laws of Motion
        i) 1st: An object's speed and direction of travel will remain constant, unless acted upon by an outside force.
        ii) 2nd Law: The change in speed and direction of an object is parallel and directly related to the total applied force on that object.
        iii) 3rd Law: For every applied force there is an equal and opposite applied force.
    d) Deformation is when an object …
        i) Responds to a applied force
        ii) Changes its shape
        iii) Changes its size
    e) Stiffness is the…
        i) Materials resistance to deformation
        ii) Amount of deflection developed for a given force
        iii) Ductility – Ability of a material to deform by application of force
            (1) Can be viewed as the flexibility of the material
        iv) Brittle – Inability of a material to deform
            (1) Can be viewed as how rigid the material is.

4) Basic Forms of Mechanical Testing
    a) Tensile Tests
        i) Measures the response of a material to pulling
        ii) Applications Examples: Rope, Cable, Back-pack straps, etc.
        iii) Show the class a rubber band being stretched
    b) Compression Test
        i) Measures the response of a material to pushing (compression)
        ii) Pillars, Chair Legs, Walls, etc.
        iii) Show the class a piece of foam being compressed
    c) Bending Tests
        i) Measure a material's ability to be curved
        ii) Looks at both pushing and pulling stresses in a material
        iii) Produces a twisting effect in materials
        iv) Bridges, Bed frame, Roof, etc.

5) Material Failure
    a) Applied force goes beyond the strength of the material
    b) Results in damage and breaking of object
    c) Shows the limit of material to handle a load
    d) Three stages to failure (i>>iii)
        i) Elastic deformation
            (1) Ability of material to deform without losing its shape
            (2) Ex: Stretching a rubber-band
            (3) Experienced initially by the material
        ii) Plastic deformation
            (1) Permanent mis-shaping of the material
            (2) Ex: Bending a paper clip
            (3) Seen after elastic deformation
        iii) Failure
            (1) Permanent separation of the material
            (2) Ex: Broken pencil tip or torn piece of paper
            (3) Final stage of failure

Appendix

Material Characterization In-class Project – (Laminated Cantilever Beam)

For this activity it is suggested that the class be broken up into groups of 2-3 students and given enough material to build one beam each.

Required Materials (per group)

1 – 4-5 feet of string or wire (Fishing line, Twine, etc.)
1 – 3/16in Foam Board Sheet
1 – 3/32in Corrugated Cardboard (The standard cardboard used in most shipping boxes)
1 – 3/80in sheet of cardboard sheet (Binder's Board)
2 – Tables of equal height that can be spaced roughly 12in apart

Required Tools

- 2 Rulers
- 1 Yard Stick
- Black Permanent Marker
- School Glue (Tacky glue works the best)
- Scissors, Safety Razor or straight edge cutting board.
- 2 C-clamps
- Small and thin piece of wood, at least 2 inches by 2 inches

Activity Instructions

1) Clear a spot on which to place a cutting mat
2) Cut a number of 2 in by 12 in strips out of the foam board, corrugated cardboard, and cardboard sheet
    a. Note: Three sheets of cardboard sheets are equal to one sheet of the other material.
    b. An example assembly can be seen in figure 2.
    c. To streamline the in-class portion of this activity, this segment can be performed as a pre-class preparation task.
3) Have each team select a material for each of the three layers.
    a. Any combination will be fine.
4) Using the glue, place a zigzag pattern across each bonding surface, note figure 2.
    a. For best results use a fine paint brush or finger to evenly spread the glue across the surface in a thin layer.
5) Sandwich each layer and gently align the edges of each layer together.
    a. Apply gentle pressure along the length of the beam. In is important to not to smash the
6) Once all of the layers are combined let the beam dry for at least 15 minutes.
    a. It is suggested that this activity is started at the beginning of the class.

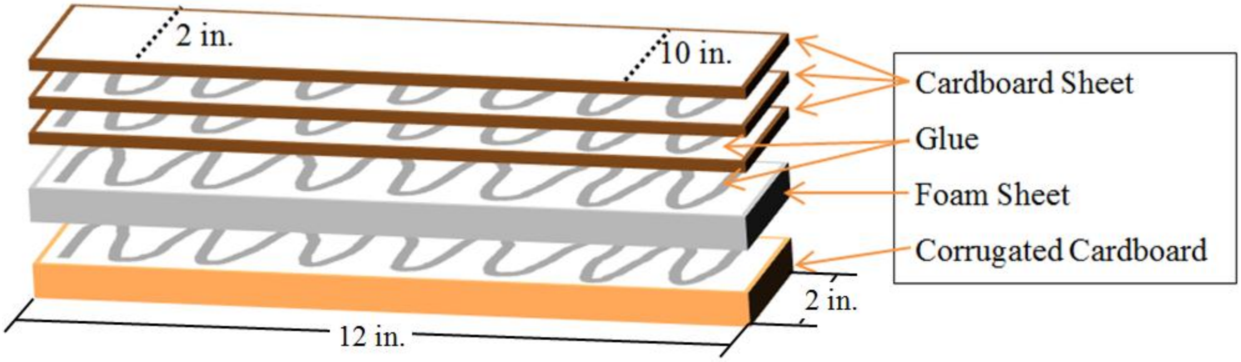

Figure 2. Possible cantilever beam design.

7) Using a 12 inch ruler measure and mark 2 inches and 10 inches from one end of the beam
8) Place the beam so that the segment with 2 inch mark is lined up with the table edge and the beam forms a 90 degree angle with the edge.
9) Tighten the C clamp so the beam is firmly secured to the table.
    a. Before tightening, place the small piece of wood between t
10) Cut a length of wire (L>12 inches) and wrap one end around the beam at the 10 inch marker made earlier.

   a. Make sure that the end is hanging one inch from either side of the beam.
   b. Wire should allow for sufficient clearance between the ground and weight to account of beam deflection.

11) At the other end create a loop and attach the weight hanger
   a. If the classroom is not equipped with a set of premeasured weights and hanger a large S hook and milk container will also work. Simply fill the container in increments with water, weighting and recording each increment.
   b. An example of the finished beam is show in figure 3

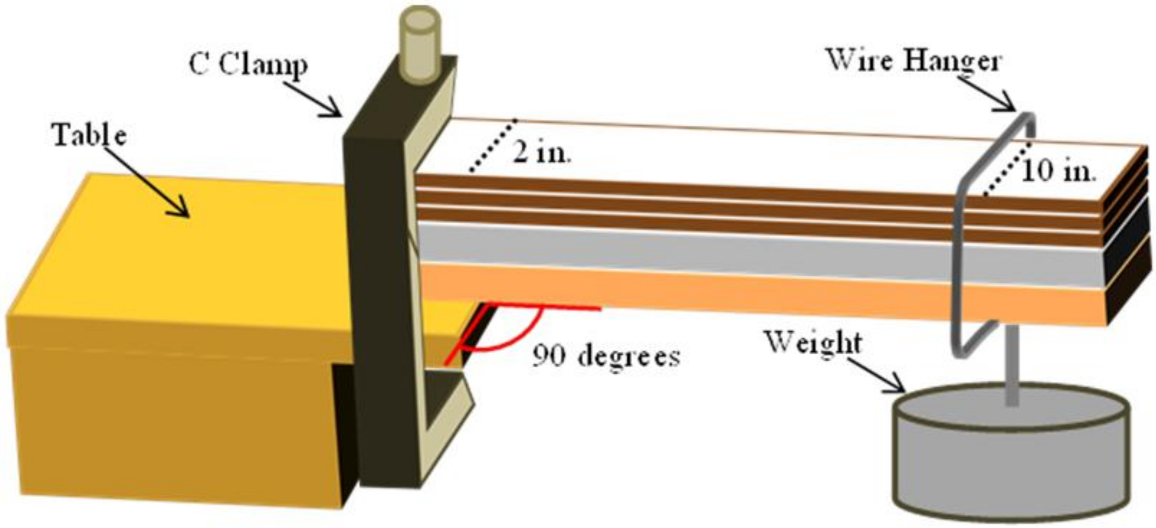

Figure 3. Diagram of mounted cantilever beam and weight hanger setup (Not to scale). The color code of the beam corresponds to the configuration noted in figure 2.

12) Measurement of beam displacement – Two options
   a. Yard Stick
      i. Take the yard stick and place it so that it is standing up vertically. Then move it close to, but not touching, the end of the beam.
      ii. Measure the location of the beam on the yard stick. This will be the initial reference point ($h_{initial}$).
      iii. Use $\Delta h = (h_{measured} - h_{initial})$ to find the displacement of the beam at each increment.
      iv. Note: it is best if the yard stick is placed so that the smallest values are at the top and increase downward.
      v. Example of this setup is shown in figure 4a.
   b. Horizontal Reference Bar
      i. Parallel to the beam attach a straight stick or ruler to the table with its extended ending matching the protruding length of the beam. This will be the displacement reference.
      ii. Measure the vertical distance between the bottom of the reference and the bottom of the beam at their very ends. This will be the starting displacement from the beam at load = 0 ($h_{initial}$).
      iii. Use $\Delta h = (h_{measured} - h_{initial})$ to find the displacement of the beam at each increment.
      iv. Example of this setup is shown in figure 4b.

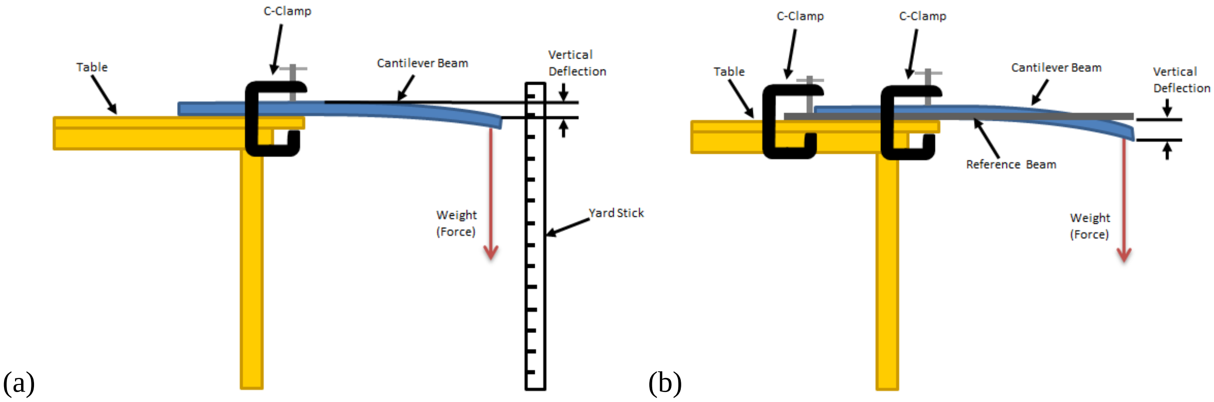

Figure 4 - (a) Vertical beam measurement system using vertical yard stick and (b) horizontal reference beam measurement system.

13) Slowly add weight to the hanger. At each increment record the vertical movement of the beam
    a. For this experiment 4-8 oz. (¼ to ½ lb) increments are the suggested range.
14) Continue this until the beam has deflected 3 inches, which will be classified as material failure.
15) Using this data plot the each point on a load (y) versus displacement (x) chart.
    a. Perform this step for each group.
    b. Note figure 5 for an example of final chart.
16) Identify…
    a. The linear portion of the graph
        i. Elastic deformation
    b. The curved portion of the graph
        i. Plastic Deformation
        ii. Buckling, Stretching, or Delamination of the material has occurred.
    c. Point of failure
        i. End of the graph
        ii. What was the final load for the displacement?
    d. Example Chart – Figure 5
        i. Specimen 1: Weak and Brittle. Mainly the development of elastic deformation
        ii. Specimen 2: Tougher than Specimen 1, but still brittle. Still largely experiencing elastic deformation. Some plastic deformation noted by the curve of the graph.
        iii. Specimen 3: Excellent Stiffness. Tough and flexible. Strongest material recorded.
        iv. Specimen 4: Weak and Brittle. Very similar response to Specimen 1, with the exception of improved flexibility.
        v. Specimen 5: Very flexible. Strong and flexible. Greatly reduced stiffness compared to specimen 3.

Post-Activity Lesson

On completely the activity review the topics discussed in the pre-activity lessons. Ask the students questions that allow them to make connections with the activity and topics such as:

1. When you placed weight on the beam, what happened to the beam?
    a. Deflection
2. How does the beam respond to the load?
    a. It bends
3. Where can this same effect investigated in the activity be seen in the everyday world?
    a. Diving boards, bridges, archery bows, See-Saws.
4. How does the activity help to place the material in terms of sustainability?
    a. Limitations of materials
5. What form of failure would best describe what was seen in the beam?
    a. Plastic deformation

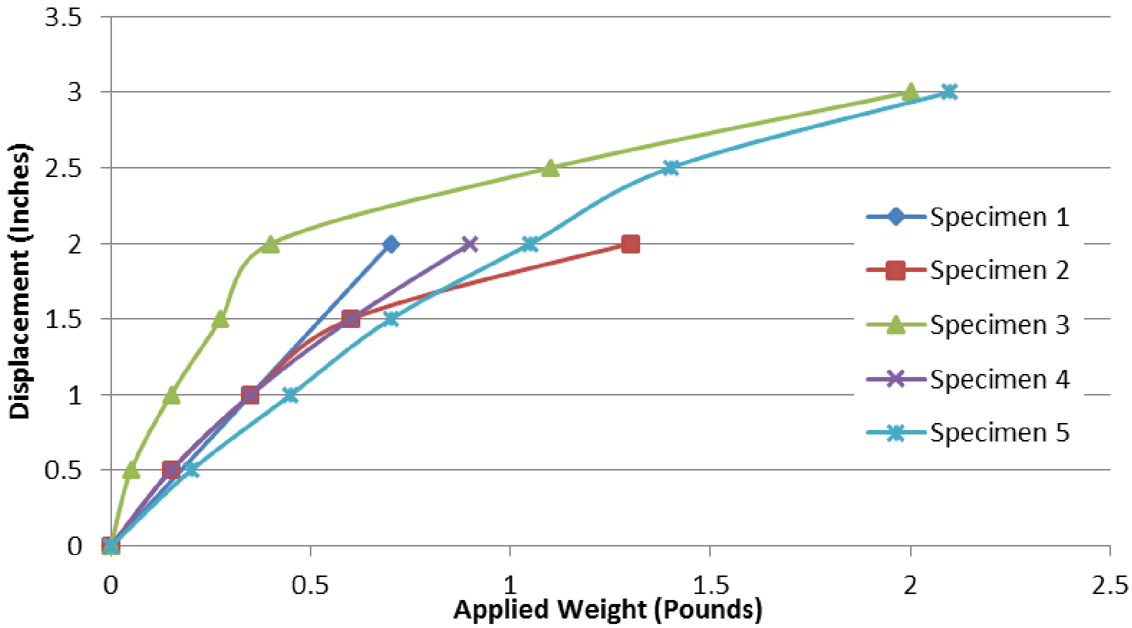

Figure 5. Chart of example cantilever beam experiment.

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Robert McCullough

Mr. McCullough is from Dothan, Alabama. He has received a B.S. in mechanical engineering and is pursuing a Ph. D. in Mechanical Engineering through the University of Alabama. He is interested in elevated and high temperature applications of light weight and advanced metal alloys systems and their use in aerospace system with a focus on sustainability based technological development.

Dr. Beth Todd

Dr. Todd is currently a Professor and the Undergraduate Program Coordinator for the Mechanical Engineering Department at The University of Alabama. She is also the principal investigator for the University of Alabama's NSF GK-12 program. She has a B.S. in Engineering Science from Pennsylvania State University and has a M.S. in Applied Mechanics and a Ph.D.in Mechanical & Aerospace Engineering from the University of Virginia. Dr. Todd's research deals with applying principles of mechanical engineering design to problems of the human body. This includes both the design and analysis of devices, particularly assistive technology, and the study of the body itself as a mechanism.

Dr. J. Brian Jordon

Dr. Jordon is currently an Assistant Professor for the Mechanical Engineering Department at The University of Alabama. He has a B.S., a M.S., and a Ph. D. in Mechanical Engineering from Mississippi State University. His research interests include microstructure-based constitutive modeling of plasticity and damage, fatigue modeling, fracture mechanics, experimental quantification of structure-property relationships, and finite element analysis of manufacturing processes. Currently, Dr. Jordon is working with the automotive industry in developing durable joining techniques for lightweight metals like aluminum and magnesium alloys.