Internet2 Event – BIG BLUE on I2

February 27, 2008

Critical Repairs: In Space and on Earth

Version 3, 2/4/08

Overview

What do you do when an important part of your car breaks? You arrange for a tow truck to take it to the repair shop. What do you do if an important part of your spacecraft breaks? Fixing it yourself may be the only option, since returning to Earth to a "repair shop" facility might not be possible.

This series of questions and activities will help you understand and appreciate some of the challenges of repairing cracks and breaks in pipes and plates. You can imagine these as parts of important systems on your spacecraft – piping systems for your water supply or air supply and panels on the outside surface.

Background

How do you measure the strength of an object? And if the object cracks or breaks, how do you measure the strength of the repair?

Question #1 - If you have a hose that is leaking or cracked and you can't replace it, how would you repair it? What causes hoses to fail? What happens when they do fail? What is included in the design of hoses to make them more resistant to failure?

In undergraduate engineering, one subject of study is Strength of Materials, which is sometimes also called Deformable Solids. At UK, the course description for this course describes it as follows:

"EM 302 Mechanics of Deformable Solids - A study of stress and strain in deformable solids with application primarily to linear elastic materials: stress and strain transformations; simple tension and compression of axial members; torsion of shafts; bending of beams; combined loading of members; buckling of columns."

Stress is a key idea in this course, describing the average intensity of the force per unit area acting inside a material in reaction to forces (or loads) acting on the outside of the material. This course considers many situations of applied force and then looks at

the internal stresses that result. Here, we'll consider only a few specific examples that will allow us to test a new material that is being developed for in-space repairs.

"Normal" stress, σ, is defined as

$$\sigma = F / A$$

where F is the force acting perpendicular to the cross section area A. The units for stress are the same as those for pressure which is also force per area, N/m^2 (Pa, Pascals) or lb/in^2 (psi). If the normal stress is acting to stretch the material, then it is called tension or tensile stress. If the normal stress is acting to squash the material, then it is called compression.

Question #2 – If you have a rectangular bar that is 2 inches wide by 0.125 inches thick by 10 inches long that is subjected to a 200-lb force as shown, determine the normal stress inside the material. Is this tension or compression?

"Shear" stress occurs when the force is parallel to the face of the area, rather than perpendicular to it. The shear stress, τ, is

$$\tau = V / A$$

where V is the force acting parallel to the cross section area A. Again, the units for shear stress are the same as those for pressure which is also force per area, N/m^2 (Pa, Pascals) or lb/in^2 (psi).

Question #3 – If you have two 1-inch wide by 0.25-inch thick by 6-inch long rectangular bars that are joined by gluing them together with a 2-inch overlap as shown, determine the shear stress in the glue.

Different adhesives are better for situations with different stresses. For example, "Super glue" holds better in tension than in shear, so if you want to disconnect two fingers joined with "super glue" the package says to gently rub them back and forth trying to peel them apart, rather than trying to pull them apart.

Dental adhesives are generally very strong, to transfer the forces from the wires and bands to your teeth, so ask the next time your braces are adjusted about the adhesives used to mount the brackets and how your orthodontist plans to get them off when your smile is done. Have you noticed the light they sometimes shine at the dentist or orthodontist? This light helps the adhesive curing reaction to take place – to harden the adhesive. Sometimes adhesive curing can be accelerated with heat, sometimes with light of certain wavelengths, sometimes with chemical catalysts.

Question #4 – Make a list of different adhesives you have used or are familiar with at home, at school, for auto repair, at the dentist, etc. For each one, include the chemical composition and instructions for using the adhesive. What would make an adhesive better for bonding one material than another?

Testing Material Strength

Measuring the strength of a material is sometimes done with a tensile test. In a tensile test, a sample of the material is prepared and clamped at either end into the test machine. The machine gradually increases the tensile force applied to the test specimen until it fails or breaks. The load or normal stress (load per cross section area) and the extension or strain (extension per sample length) in the material are recorded. The force-extension plot and the stress-strain plot are useful for characterizing materials and for understanding how they will behave in various applications. In the images below, samples of potential wing fabrics are tested to failure with a tensile test.

Figure 1 The templates that were used to prepare the fabric specimens

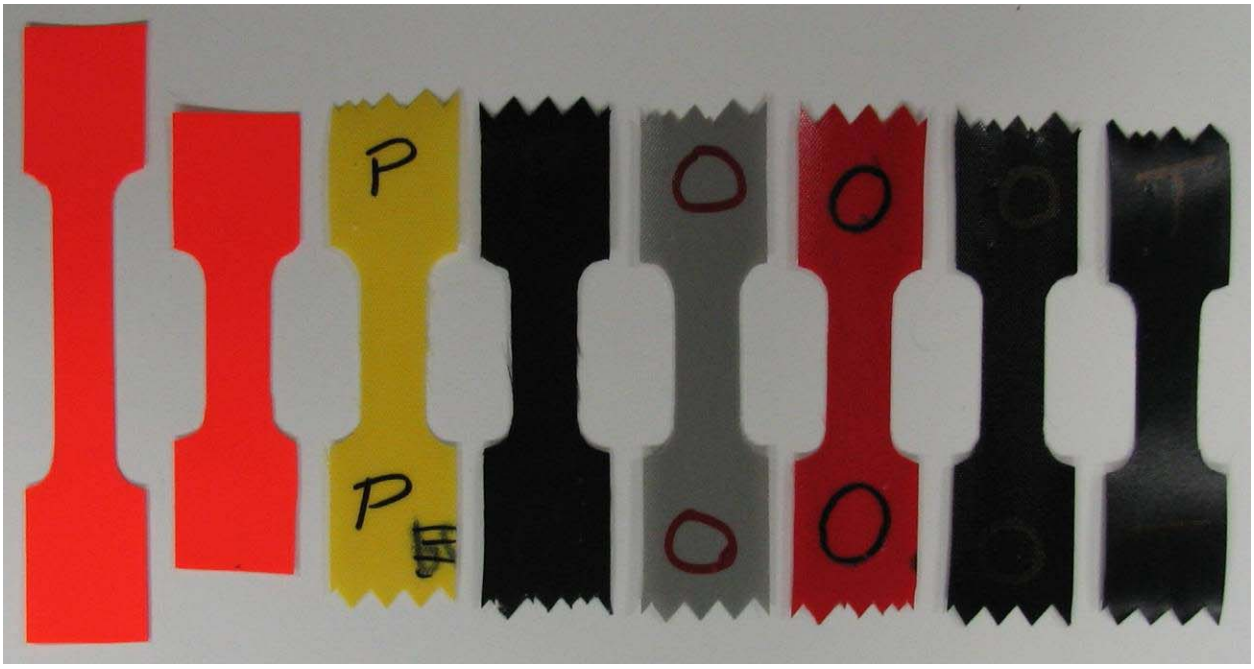


Figure 2. Tensile specimens before testing, in order from left: (Orange-L, Orange-S, Pack Cloth-Yellow, Pack Cloth-Black, Oxford-Grey, Oxford-Red, Oxford-Black, Tafetta-Black)

Figure 3. Tensile testing setup

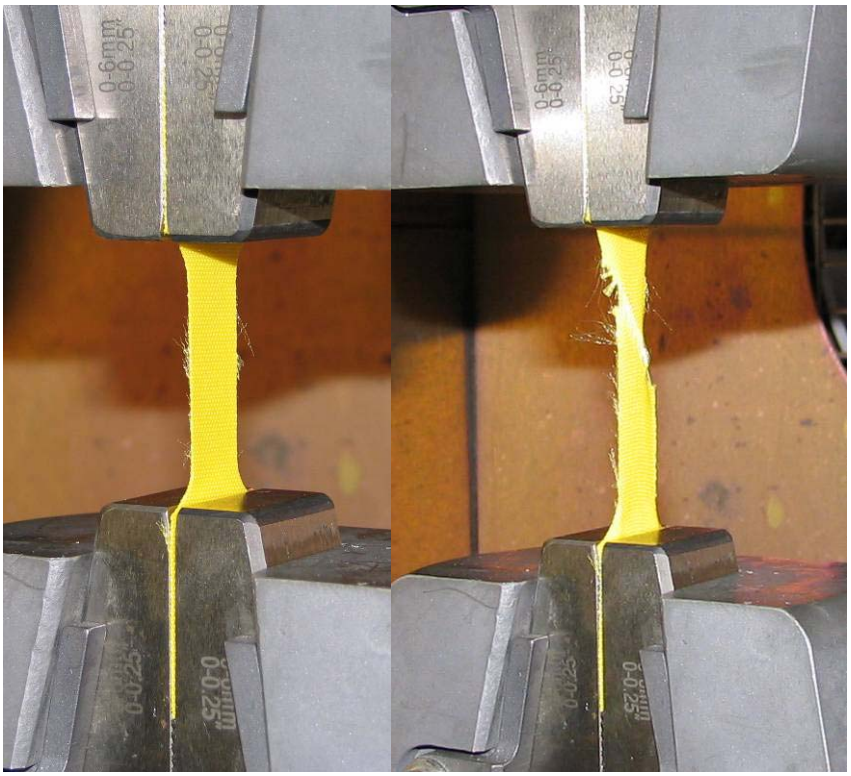


Figure 4. Example of a tensile specimen before and after testing (Pack Cloth-Yellow)

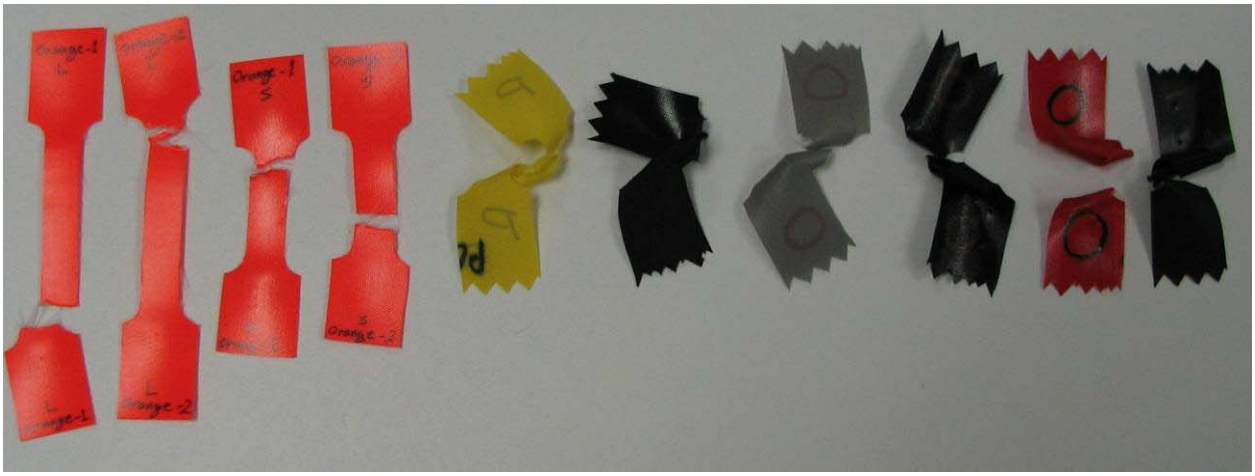


Figure 5. Tensile specimens after testing, in order from left: (Orange-L, Orange-S, Pack Cloth-Yellow, Pack Cloth-Black, Oxford-Grey, Oxford-Black, Oxford-Red, Tafetta-Black)

Question #5 – A spread sheet with data from the fabric tensile experiments is available at the following web address:

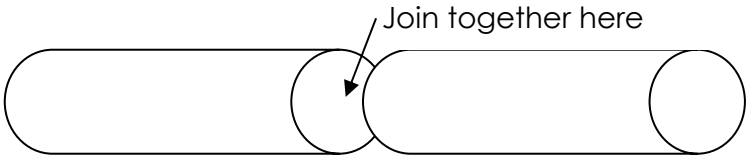
http://www.engr.uky.edu/~bigblue/I2Event/Fabric_Tensile_Tests.xls

Plot the force-extension results for each sample. Plot the stress-strain results for each sample. What cross section area do you use to determine the stress? What length do you use to determine the strain? What is the strength of each material? At what force did they fail? At what stress? Comment on differences you see in the tested samples and in the resulting data. What do you think will change if the test is repeated at a low temperature, say -50□ F? Think about fabric and how if reacts under load. These are coated fabrics, like you would find in a tent or gym bag. What has not been considered in this testing?

Pre-Event Activity

This second pre-event activity includes an assignment to join together two pieces of pipe, tubing or similar round objects and test the strength of your "repair". Be sure to make notes of everything you do during the repair process, including the environmental conditions such as temperature and humidity.

Challenge #1 – The goal of this challenge is to join together two wooden dowels or two pieces of tubing "end-to-end" producing the strongest repair with the least weight (less weight is always important in space). For the BIG BLUE I2 Event, tubes of approximately 1/2-inch outside diameter will be used, so that same size here will be consistent with the activities to follow the event. Use the list from Question #4 above or gather together a selection of adhesives. Consider tapes as an alternative joining method, comparing various tapes to various adhesives. What are other joining options for two round objects that need to be secured end-to-end?



Weigh the two pieces before the "repair" and again after the repair and determine the added weight. Tabulate data to compare the repair alternatives including weight before and after, and time to complete the repair. Include several samples for each technique to be able to understand the repeatability of the repair process as seen in the variability of the tested strength of the repair. Have a number of samples with identical repair technique be prepared by one person, but also have a number of samples with the same technique be prepared by different people. Do some samples in different temperatures (outside and inside).

Challenge #2 – Devise an experiment to measure the strength of your repair. Since we are joining two round pieces end-to-end, design a test that can be used to load the joined sample axially, along the length of the tubes. You will need to measure the load (force) on the sample for increasing loads until the "repair" fails, but if you can, also measure the extension under loading for each load before failure occurs. Determine the stress in the repair for each load and at failure. Computing stress will be different for different approaches (glue versus tape or others). What is the area over which the force is distributed for the repair? How can you compare different repair approaches to each other? Tabulate and plot your results. Don't forget that repair weight matters, so if two repair techniques result in the same strength, the lighter one will be preferred. If different people join the samples using the same technique, do the results vary more than if the same person does each sample the same way? If a repair product is being developed for the general public to use which of these results for repeatability is useful, and why?