FLORIDA A&M UNIVERSITY - FLORIDA STATE UNIVERSITY
COLLEGE OF ENGINEERING

Senior Design I

EML4551C

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Design Project 1

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Midterm I Report

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Project Overview

For certain materials, it becomes very difficult to find compression data depending on the material properties. Cummins is having this problem with their gasket materials. Parker Harwood, our graduate consultant, worked with Cummins over the summer and studied these gasket materials. He is the one who proposed creating a biaxial test rig to gather biaxial tension data. This system must be able to test a wide range of gasket materials spanning from rubber to a polymer-reinforced fibrous paper, which will all be discussed further. There are certain ways to attack this system with different pros and cons each way. This will also be discussed in a later section.

Background

Polymers

For centuries materials such as wood, rubber, and silk have been used. These naturally occurring materials are polymers. They are inexpensive to produce and are organic in origin. Similar to metals the properties of a polymer is dependent on the structure of the atomic bonding within that material. Because of the organic aspect of the material the bonds are covalent and molecular chains are formed. The mechanical characteristics of polymers happen to also be very sensitive to temperature, the strain rate, and the environment it is exposed to.

A stress-strain curve for a semicrystalline polymer is displayed in Figure 1. In polymers there are both ductile and brittle modes of fracture possible. They also can experience elongations greater than 1000%. The impact the strain rate has on the material cannot be emphasized enough. In fact decreasing the rate of deformation has a similar effect on the stress-strain curve as increasing the temperature. The stress-strain curve depicts a different type of behavior than metals. Once a small neck forms in the gauged section the molecular chains become oriented; this means that they align parallel with the elongation direction. This inhibits deformation and the neck propagates along the gauged section.

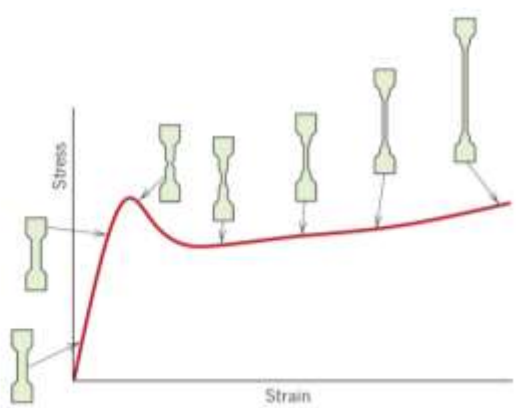


Figure 1: Tensile stress–strain curve for a semicrystalline polymer[1]

As seen in Figure 2 three very different types of stress-strain behaviors are possible. Curve A is a brittle polymer that fractures as it is deforming elastically. Curve B is a plastic polymer; this material experiences an elastic region before yielding. This is followed by plastic deformation and then fractures. Sometimes fracture occurs at a greater stress than the yield stress. The material for Curve C is an elastomer type material; these experience large recoverable strains at low stress levels. The rest of the material background was concerned with the deformation behaviors of elastomers and how they are formed[1].

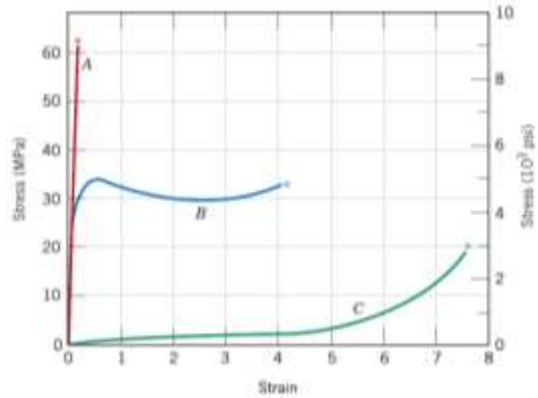


Figure 2: Stress-strain behavior for a polymer (A) brittle (B) plastic (C) elastomer[1]

Elastomers

The gasket material that will be tested in the biaxial tensile machine is a nearly incompressible elastomer capable of handling high temperatures. Elastomers have the ability to achieve large deformations and then elastically spring back into shape. The modulus of elasticity is quite small and varies linearly since the curve is no longer linear as it is for metals.

Figure 3 shows the crosslinked polymer chains that makeup the structure of elastomers. While unstressed the crosslinked chains are coiled and kinked; once a stress is applied the elastic deformation occurs by the straightening and unfurling of the chains. When the elastomer is released the coils snap back into the original shape. There are several criterions that a material must possess if it is to be considered an elastomer. First, it cannot easily crystalize. Second, the chain bonds must be relatively free to move and respond to the applied force. Third, for the elastomer to experience the huge elastic deformations that they do the plastic deformation must be delayed.

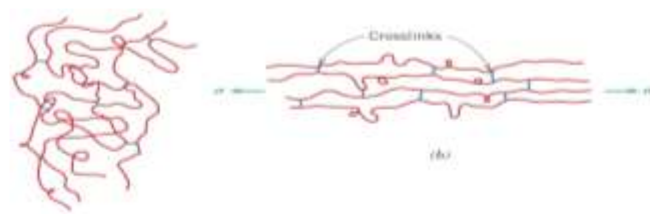


Figure 3: Representation of the crosslinked chains molecules found in polymers, and how they react with applied stress[1].

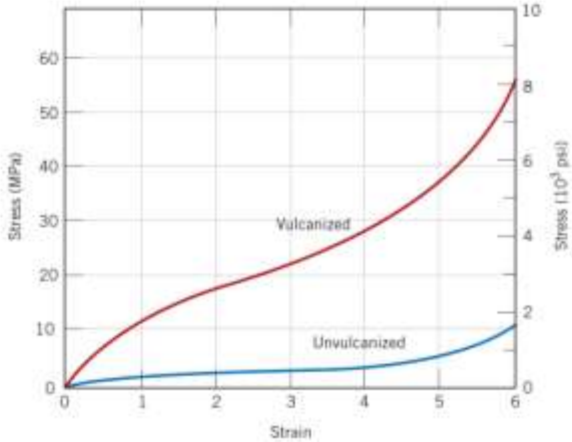


Figure 4: Stress-strain curve to 600% elongation for natural rubber both vulcanized and unvulcanized[1].

Crosslinks are formed by a process called vulcanization. This is normally an irreversible chemical reaction that is carried out at elevated temperatures. Vulcanization enhances the tensile strength, modulus of elasticity, and resistance to degradation. Figure 4 shows a stress-strain curve for vulcanized and unvulcanized rubber[1].

Existing Biaxial Machines

Part of the purpose behind this project is that the existing biaxial machines were not ideal for the purpose of Cummins' gasket material testing. This can be attributed to several instances of cons in the design. Figure 1 shows a biaxial machine pulling along two different axes, as the name suggests. The problem with this design is that the materials needed to be tested are a variation of polymers. This causes the material along the edge that is not gripped by the test rig to bow inwards while the gripped material is pulling outwards. This is a function of the material's elasticity and lack of stiffness.

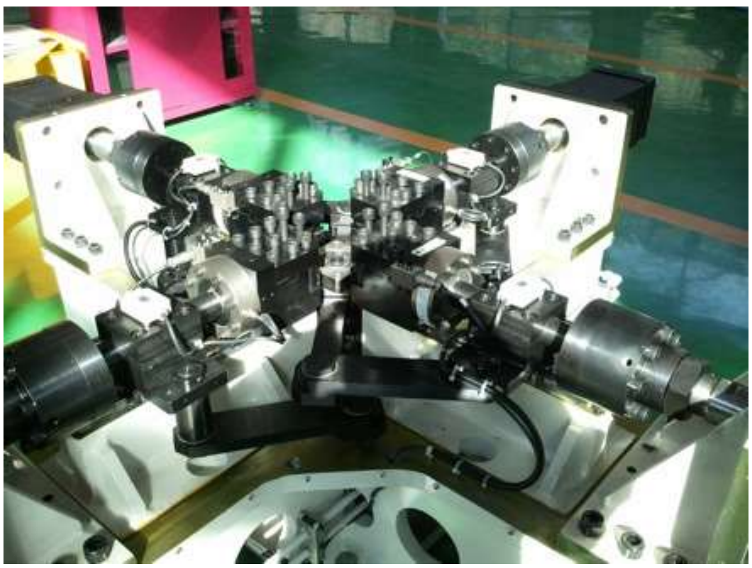
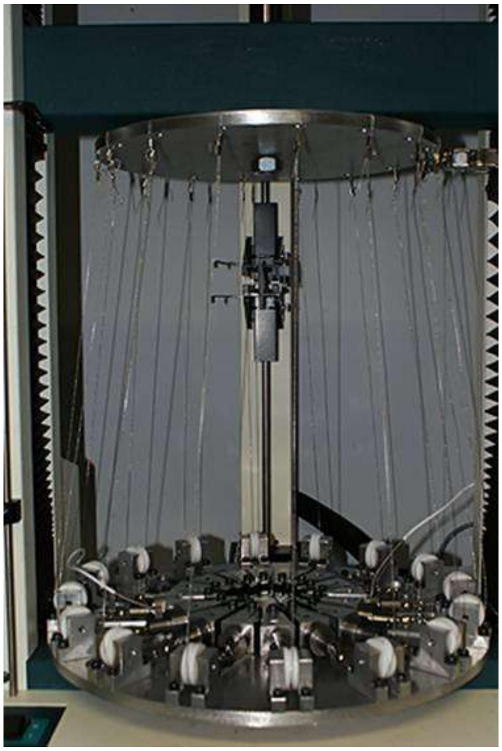


Figure 5: Tensile Machine Pulling Along Two Axes

Something a little closer to what we're searching for in our design can be seen in Figure 2. This is a multiaxial machine that will take away the unevenness in stretching the material. The problem with this particular design is that the material will be testing will need to be a much bigger specimen size then what is required in this fixture. Some of the gaskets we have are composed of a polymer reinforced, fibrous paper that experience strain depending on the orientation of the fibers. If the testing specimen is larger, the larger surface area should allow for some sections to have no strain, which will be found in prototype testing later.

Another multiaxial design can be seen in Figure 3. This is much more similar to something we'll be designing. The main problem with this is that the force applied to the



specimen is done by a deadweight type of technique. That means that they use variable weights added to each pulley individually. This is a problem because this really limits how much weight is added to each pulley. It makes it very complicated to add a lot of weight and keep the weight attached. This is something that can easily be addressed in our design.

Figure 6: Multiaxial Test Machine

Figure 7: Another Multiaxial Test Rig

Ways to Measure Force

One difficult dimension into designing this system is how to measure the force applied during the test. This can be addressed in several ways. One of the more effective ways we have considered is the use of a spring. A spring solves many problems in designing a system. Having a spring with a known spring constant allows the option of developing a way to precisely measure the distance stretched to use Equation 1 to find the force applied. The downside to this is having to develop a system to measure the stretch in the spring.

A way to combat this problem is to return to the original objective and utilize a MTS machine to stretch our specimen. This solves every problem because there is already a load cell in a MTS machine that will precisely measure force applied to the whole specimen. The downside to this is that we won't be able to variably change the force applied to each pulley like you can when using the machine in Figure 3, but that could be a necessary trade-off as far as ease of design and design is concerned.

$$\text{Equation 1: } F = -k * x$$

Gripping Techniques

One of the most important parts of our device will be the grips. As the interface between the applied force and the sample there are some basic requirements for an accurate result to be achieved. The grips should minimize the deformation of the sample. The reason that the grips should minimize the deformation is that as the area of the sample is reduced, the stress is increased. A large deformation makes it more likely that the sample will fail at the grip. Ideally we would like to be able to have the failure occur in the center of the sample, and if it fails at a low enough stress near the grip then no useful data will be acquired.

Another important requirement of the grip is that it needs to maintain a planar alignment of the sample to prevent the introduction of shear forces or bending moments. In order to accomplish this the grips will need to be precisely manufactured to the same size and mount to the carrier at exactly the same height. To help keep the grip planar the carrier will be inserted into a track to better keep it constrained.

The grips have to be able to hold the sample through the entire loading process without slipping. In order to accomplish this, the grips will need to create friction between themselves and the sample. There are two basic ways of doing this, we can make the surface of the grips very tacky, or we can create a raised geometry of horizontal lines or a pattern of spikes, this will increase the amount of surface in contact with the grips while minimizing the overall compression of the sample. An important part of the grips ability to hold the sample will be the manner in which they are tensioned. We will investigate a few methods, the first method will be a spring, but this approach may lead to problems, it will be difficult to adjust for different types of materials and may be more difficult to maintain the planar alignment. A more likely solution would involve screws or bolts, this would allow the user to vary the tension easily, and the use of a single bolt that draws both of the grips together at the same rate would likely be the best method to maintain planar alignment.

Finally, the grips and carrier will be custom made pieces, therefore it is important that they are a strong point in the design, it will much easier for the customer to repair a standard sized cable than a custom machined piece. Due to the cyclical loading cycles it will be very important to design a grip and carrier that can not only endure the forces placed on it but will not fatigue over time.

An outside the box solution that we will examine involves a grip that does not contact the sample. Instead a highly elastic material would be adhered to the sample and the grips would actually pus outwards on this surface.

Finite Element Models

Finite element analysis is a computer modeling protocol that predicts the behavior of materials of a given composition and geometry based upon their material properties. The gaskets which are the focus of our project are rubber and rubber coated fiber materials which are generally analyzed as incompressible or nearly incompressible. There are great challenges in analyzing these types of materials. Their properties and performance are much less well understood than the properties of other materials such as metals, plastics and fibers. Many different mathematical models have been developed to attempt to predict their behavior. The most common are the Neo-Hookean, Mooney-Rivlin, and Ogden models. However there are even many subsets within these models. Fortunately, they all require the same data in order to achieve the best results.

Finite element models of the type above can be constructed using only one or both of the uniaxial tension and pure strain data sets. Unfortunately, this data produces a rather inaccurate model of the materials behavior. Below, you can see the stress strain graphs of an Ogden based model produced only using the uniaxial tension data on the left, and on the right is the graph of the same material with the equal biaxial tension data included, the improvement in the models ability to predict the material's behavior is remarkable.

------insert graphs from powerpoint here

Models predicting the behavior of incompressible or nearly incompressible materials all produce the most accurate results when given three fundamental data sets. These are the stress-strain relationship of the material in pure shear, uniaxial tension and uniaxial compression. Given an MTS machine it is very easy to develop the test sample geometry and proper gripping techniques to acquire both the pure shear and uniaxial tension data. Unfortunately due to frictional forces developing shear and tension forces it is impossible to get reliable data from a uniaxial compression test. Given this problem, a pure equal biaxial tension test has been developed. Due to the nature of incompressible materials if a sheet of incompressible material is radially stretched in all directions equally, the material will compress. Given the stress and strain data from the equal biaxial test one can rather easily compute the stress strain relationship for compression using Mohr's Circle. In order to get the best data it is important to induce a pure stress state in as large of an area as possible.

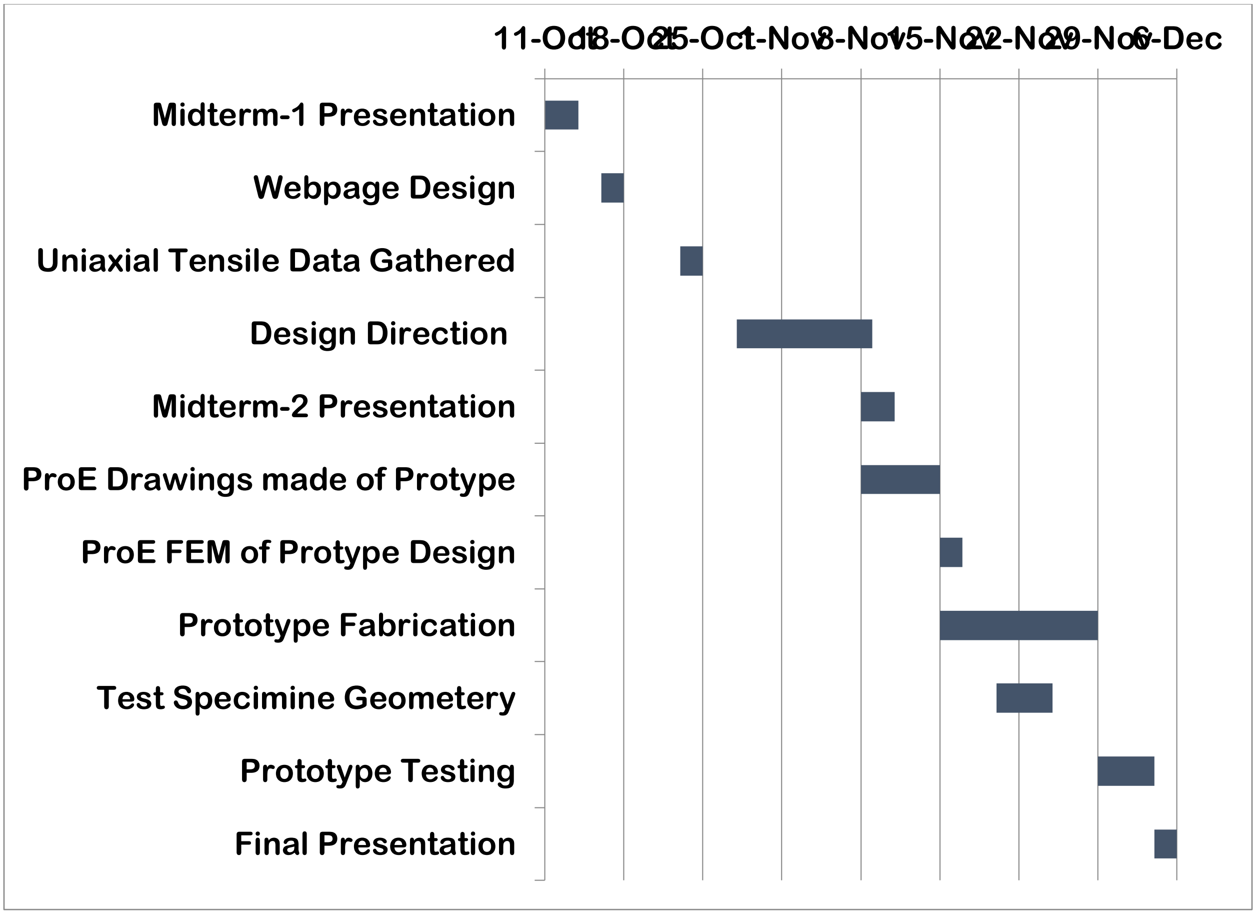
Risk and reliability Assessment & Environmental and safety

With any machine, there runs a risk for safety without the proper training. This machine will not be any more danger than operating a typical MTS machine because it should be able to be operated without a significant amount of training, and the operation should be consistent from each test to the next. There will be no real environmental safety because all testing will be done in a lab with the gasket materials. All scraps will be disposed of according to Cummins protocol.

Conclusions

Future plans for prototype and others

Gantt chart, resources, Budget



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