MEMO.

To: Dr. Bales  
From: Group 3  
Date: May 14, 2004  
Re: Photoelasticity  
Final Report - ACKT

SUMMARY AND RECOMMENDATIONS.

During our final project, we researched photoelasticity, plane versus circular polariscopes, structures of polariscopes and how they work, and isoclinic and isochromatic fringes. We built our own polariscopes using a green LED array as the light source, and observed different types of stress on different types of plastic (acrylic and polycarbonate) with different number of notches. We successfully obtained images of superimposed isoclinic and isochromatic fringes using the plane polariscope, and images of only isochromatic fringes using the circular polariscope. We separated the two different fringes by subtracting the images taken with the circular polariscope from the images taken from the plane polariscope. We were also able to predict the stress in multiple notches using the stress patterns observed in plastics with one or fewer notches. In addition, we obtained many aesthetic images, such as the MIT logo under stress, and submitted it to the MIT Spotlight. Finally, we concluded that as we increase the load on the plastic, we get more isoclinic fringes and finer isochromatic fringes. Also, we found that acrylic is not a good material to use to study stress, because the stress patterns are not visible if the force is applied perpendicular to the plane of view.

For future related work, we recommend:

- The use of a circular polariscope to study isochromatic fringes.
- That a study on images via plane vs. circular polariscope will be interesting and feasible.
- That a study on stress patterns vs. elasticity of the material will also be interesting and feasible.

BACKGROUND.

For our final project, we were interested in studying how we can visualize strains in plastic specimens, as well as how we could use these visualizations to analyze strain in the specimens. In particular, we focused our research on strain in polycarbonate, notched plastics strips. See PROCEDURE. This section is organized in the following manner. In the first subsection Linear and Circular Polariscopes, we present two basic types of apparatuses, linear and circular polariscopes, which are commonly used to visualize stress patterns in materials. We discuss how they are structured and what we expect to see via these apparatuses, respectively. In the second subsection Two Types of Stress Patterns, we explain that there are two basic types of stress patterns viewable via a polariscope, isochromatic (wavelength-related) and isoclinic (stress-related) fringes. We also discuss why we see a super-positioning of both isochromatic (wavelength-related)
and isoclinic (stress-related) fringes via a linear polariscope, and why we see only isochromatic (wavelength-related) fringes via a circular polariscope. In the third subsection Crack Propagation, we briefly discuss the challenges of studying crack propagations in materials, a field known as Fracture Mechanics. Finally, we present some final project goals, which we thought were feasible to reach and/or seemed interesting to try to reach, given the background research presented in this section.

**Linear and Circular Polariscopes.** A polariscope is an apparatus that utilizes the properties of polarized light. Polariscopes are used for a wide ranges of applications. Specifically it is used for photoelasticity, studies of strain in materials using optics. There are two basic types of polariscopes, the linear (also known as plane) polariscope and the circular polariscope.

The basic, structural design of the linear polariscope can be described as follows. A linear polariscope is composed of the following arrangement of equipment: (1) a light source, followed by (2) a (linearly) polarized filter, technically known as the polarizer, followed by (3) the specimen, which we are interested in studying, followed by (4) another (linearly) polarized filter, technically known as the analyzer, and finally (5) the camera. The two (linearly) polarized filters, the polarizer and the analyzer, are positioned such that the filters are parallel to each other, and such that the orientations of their polarizations are perpendicular to each other. See Figure 3(a) for a diagram of our linear polariscope, in **PROCEDURE.** As explained further in the next subsection, **Two Types of Fringes,** there are two basic types of stress patterns or fringes, isochromatic (wavelength-related) and isoclinic (stress-related) fringes. As further explained in the same subsection, when we use a linear polariscope, we see a super-positioning of both types of fringes in specimens.

The basic, structural design of the circular polariscope is similar to that of the linear polariscope and can be described as follows. A circular polariscope is composed of the following arrangement of equipment: (1) a light source, followed by (2) a (linearly) polarized filter, technically known as the polarizer, followed by (3) a quarter-wave plate, followed by (4) the specimen, which we are interested in studying, followed by (5) another quarter-wave plate, followed by (6) another (linearly) polarized filter, technically known as the analyzer, and finally (7) a camera. Again, the two (linearly) polarized filters, the polarizer and the analyzer, are positioned such that the filters are parallel to each other, and such that the orientations of their polarizations are perpendicular to each other. The quarter-wave plates are also positioned such that they are parallel to each other and to the polarizer/analyzer. The quarter-wave plates have an intrinsic orientation, are positioned such that their orientations are 90 degrees apart, and such that the light which passes through the polarizer, the quarter-wave plates, and the analyzer is either the dimmest (the darkfield setting) or brightest (the lightfield setting). See Figure 3(b) for a diagram of our circular polariscope, in **PROCEDURE.** As further explained in the next subsection, **Two Types of Fringes,** when we use a circular polariscope, we see only isochromatic (wavelength-related) fringes in specimens.

**Two Types of Stress Patterns.** First, it is important to note that we are able to see stress patterns in transparent plastics because of the following plastic’s property. Under stress, a transparent plastic acts as a wave plate, a material which resolves light into two components along two perpendicular axes, a slow axis and a fast axis, aptly named because a wave plate introduces a phase difference between the two components.

As mentioned in earlier subsections, there are two basic types of stress fringes as viewed via a polariscope, isochromatic (wavelength-related) and isoclinic (stress-related). When we view a stressed specimen via a linear polariscope, we see both types of fringes. To better explain what these types of fringes are and why we see both types in a stressed specimen when we use a linear polariscope, let us step keep track of the the light components as we go through each optical element of a linear polariscope. Let the light coming out of the polarizer be \( ke^{iωt} \), and, therefore, its real component be \( E_1 = k \cos \omega t \). Then, because a stressed, transparent specimen acts like a wave plate, as \( E_1 \) passes through the stressed specimen, it resolves into two components \( E_2 \) and \( E_3 \) along perpendicular axes. If we let \( θ \) be the angular difference between these axes and the axes, as defined by the polarizer’s and the analyzer’s polarizations, we can define \( E_2 \) and \( E_3 \) in
terms of $E_1$ and $\theta$.

\[
E_2 = E_1 \sin \theta = k \sin \theta \cos \omega t \quad (1)
\]

\[
E_3 = E_1 \cos \theta = k \cos \theta \cos \omega t \quad (2)
\]

Since the specimen acts as a wave-plate, it also induces a phase difference $\delta$ between the light components $E_4$ and $E_5$, which are the light components, corresponding to $E_2$ and $E_3$, which come out of the specimen. Let us arbitrarily choose $E_2$ to be in the direction of the slow axis, and $E_3$, in the fast axis. Then, we can write $E_4$ and $E_5$ in terms of $\delta$.

\[
E_4 = k \sin \theta \cos \left( \omega t - \frac{\delta}{2} \right) \quad (3)
\]

\[
E_5 = k \cos \theta \cos \left( \omega t + \frac{\delta}{2} \right) \quad (4)
\]

Because the light component which passes through the analyzers are the components of $E_4$ and $E_5$ which are parallel to the polarization of the analyzer, the light which passes through the total amount of light which passes through the analyzer can be defined in terms of $E_4$, $E_5$ and $\theta$.

\[
E_6 = E_4 \cos \theta - E_5 \sin \theta
\]

\[
= k \sin \theta \cos \theta \cos \left( \omega t - \frac{\delta}{2} \right) - k \cos \theta \sin \theta \cos \left( \omega t + \frac{\delta}{2} \right)
\]

\[
= \frac{k}{2} \sin 2\theta \left[ \cos \left( \omega t - \frac{\delta}{2} \right) \cos \left( \omega t + \frac{\delta}{2} \right) \right]
\]

\[
= k \sin 2\theta \sin \frac{\delta}{2} \sin \omega t \quad (5)
\]

Since light intensity is proportional to the square of the light’s amplitude, the light intensity that is recorded by a camera can be expressed as $I = I_d \sin^2 \frac{\omega t}{2}$. Thus, the light intensities are zero when either (1) $\delta = 2m\pi$ or when (2) $\theta = 0$ or $\pi/2$. The patterns created by Case (1) are the isochromatic fringes and the patterns created by Case (2) are the isoclinic fringes [1]. Note that the fringes are the black bands, where there is an absence of light. Thus, we can see both types of fringes in a specimen when viewed through a linear polariscope. Figure 1(a), depicts the super-positioning of isochromatic and isoclinic fringes of a stressed, clear plastic, as seen via a linear polariscope [4].

Through a similar procedure and assuming a darkfield setup of the circular polariscope, we obtain the intensity of light as $I = I_d \sin^2 \frac{\omega t}{2}$. Thus, when we use a circular polariscope, we see only isochromatic fringes.

Note that the isoclinic fringes occur when the slow and fast axes are parallel or perpendicular to the axes, defined by the polarizer’s and the analyzer’s polarizations. Thus, every point of an isoclinic, a black band in an isoclinic fringe, have the same direction of principal stress direction [2]. Also, note that the isochromatic fringes occur whenever the light components from the specimen, $E_4$ and $E_5$, are in phase. The name 'isochromatic fringe' comes from the fact that if we use a white light source, the isochromatic fringes are useful in that they are wavelength-dependent [3]. However, isochromatic fringes are also created by the strain of a specimen. On the other hand, the isoclinic fringes seems more directly useful for visualizing the strain, because the direction of the isoclinic fringes are the directions of the strain.

**Crack Propagation.** The study of crack propagation is a whole research field called Fracture Mechanics, and is not a trivial study. First, researchers in the field rarely consider mathematically modeling the crack propagation velocity. Researchers in the field consider its elastic energy dissipation, which is mathematically defined as $dE/dx$, where $\epsilon$ is the strain, and $x$ is the crack extension, the length of the crack. The elastic
energy stored in our specimen by loading it with some force is given by

\[ U = \int \sigma \, d\varepsilon \, dV \], where \( \sigma \) is the stress, \( \varepsilon \) is the strain, and \( V \) is the volume.

As the crack propagates generally in a certain direction, many tiny cracks perpendicular to the main, largest crack form, dissipating a lot of the elastic energy. From this, we hypothesized that if we were to capture a crack propagation using HSV, we would find that the velocity of the propagation would decrease significantly as the crack propagated.

**Goals.** From the background research above, we concluded that the following project goals were feasible and or interesting to challenge.

- To study the effects of different loads on stress patterns
- To obtain images of superimposed isoclinic and isochromatic fringes using plane polariscope, and images of only isochromatic fringes using circular polariscope
- To separate the two different fringes
- To study the stress patterns of plastic sheets with notches
- To predict the stress of multiple notches using the stress patterns in one or fewer notches
- To capture aesthetic images
- To study crack propagation in the specimens
PROCEDURE.

List of Equipment.

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<td>The Edgerton Center</td>
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Stress on Notched Strips.

Stress-Control Apparatus. The majority of our results were achieved using a stress-application device that we created in the Edgerton Center. The stress-application device allowed us to vary the degree of stress applied to different specimen in a controlled fashion, so that we could gain a visual understanding of how stress patterns changed with varying loads of applied pressure.

The stress apparatus was created mainly using two short and wide blocks of wood and different sized C-clamps. We cut corresponding slits of varying widths into the two wooden blocks to enable us to insert different sized plastic strips in our apparatus. We then used small C-clamps to fasten the wooden blocks in parallel with each other on a long wooden board, at a distance of 6 inches apart. A plastic strip could then be inserted perpendicularly into a set of slits in the wooden blocks and held firmly in place. Finally, a C-clamp was fastened at the midpoint along the length of the strip, and under the table, from where point pressure (or stress) could be applied to the specimen by tightening the clamp. Figure 2 diagrams the stress-application device that was used in our study.

![Diagram of stress application devise](image)

Figure 2: Diagram of our stress application devise.

Linear Polariscope. We used a linear polarscope to examine simultaneously the isochromatic and iso-clinic fringes in the plastic strips under the stress apparatus. The setup for the linear polarscope consisted of
two thin sheets that made up the polarizers and a green LED array. A white sheet of paper was placed over
the front of the green LEDs to make the intensity of the emitted light more uniform across the surface by
diffusing the LEDs. The stress apparatus holding the specimen was then placed in front of the green LEDs,
in between the polarizer (closer to the LEDs) and the analyzer (further from the LEDs, on the outside).

The polariscope was placed on top of a table, with the D100 camera positioned in axis with the specimen,
at the same height as the table. Figure 3(a) shows the setup of the linear polariscope and the D100 used to
capture the specimen under stress.

![Diagrams of our physical setups. (a) Our linear polariscope. (b) Our circular polariscope.](image)

**Circular Polariscope.** We used a circular polariscope to view the isochromatic fringes in the plastic
strips under the stress apparatus. The setup for the circular polariscope was similar to that of the linear
polariscope we had used earlier. To create the circular polariscope we made slight additions to the linear
polariscope previously described. Two quarter-wave plates were introduced to the old setup - one plate was
attached in front of the polarizer, while another was attached to the back of the analyzer facing the stress
apparatus. The two quarter-wave plates were positioned in perpendicular around a common axis running
through their center. The set of plates were simultaneously rotated - while perpendicular to each other -
until they were positioned in a way such that it was brightest when looking through the analyzer (lightfield).
As was the case with the linear polariscope, a white sheet of paper was placed over the front of the green
LED array to make the intensity of the emitted light more uniform across the surface. The stress apparatus
holding the specimen was then placed in front of the green LEDs, in between the polarizer (closer to the
LEDs) and the analyzer (further from the LEDs).

The polariscope was placed on top of a table, with the D100 camera positioned in axis with the specimen,
at the same height as the table. Figure 3(b) shows the setup of the linear polariscope and the D100 used to
capture the specimen under stress.

**Capturing Fringe Patterns using the D100.** With our setup for the linear and circular polariscopes
as diagramed above, we systematically took pictures of our specimen (under different loads of stress), using
the D100 camera. In the beginning, we had to adjust the aperture and shutter speed of the camera - to avoid
both over-exposure and under-exposure of our images - by trial and error. We were extremely cautious in
this early segment of the lab, so that we would obtain images that would provide us with reasonable results
for our later analysis.
Preparing the Specimen With Notches. We primarily used polycarbonate strips of plastic as specimen for our study. Given our limited resources and time constraint, we particularly chose to study thin rectangular strips of polycarbonate plastic of two distinct thicknesses: (i.) 1/4” and (ii.)1/8”. In addition, we cut different numbers of notches in the plastic strips. For our study we used two different types of notches: thin slits and thin triangles; most of the cutting was performed with a band saw in the Hobby Shop by a member of the group.

In overview, we prepared as the specimen two different sets of plastic strips and a control plastic strip for each of the thicknesses mentioned above. The first set of specimens included plastic strips with: (i.) a triangular notch cut symmetrically at the bottom and along the midpoint of strip, (ii.) two triangular notches spaced symmetrically apart, along the bottom of the strip. The second set of specimen included plastic strips with: (i.) a thin lined slit cut symmetrically at the bottom and along the midpoint of strip, (ii.) two thin lined slits spaced symmetrically apart, along the bottom of the strip. We used as a control variable, a plastic strip of polycarbonate plastic with no notches.

Capturing images with the D100. Our setup for taking pictures of the different specimens placed in the polariscope required the coordination of four team members. One person was needed to control the room light and turned them off before capturing each image. Another person was needed to place the plastic strips into the apparatus and control the degree of stress exerted on them with the C-clamp. A third person was needed to operate the D100. Finally, a fourth person recorded data during the course of our experiment.

We initially captured images of the plastic strip with the absence of notches to be used as a control for later comparison with other images of plastic strips with notches. Thereafter, we ran through multiple trials where we captured images of the different strips with different types and a different number of notches from each of the two sets of prepared specimen. As of great importance, it should be stressed that in the process of our experiment, our entire setup was kept static. The only parts of the experiment we varied were the specimen that we placed in our apparatus and the quarter-wave plates placed in front of the polarizer and analyzer - in addition to the applied stress load.

Using our static configuration of the D100 and the setup of the experiment, we systematically captured images of each specimen in the following fashion. We would first place the specimen into the stress apparatus or more generally, in our linear polariscope. With an initial application of minimal stress (just enough to hold the specimen in place) using the C-clamp, we would take a picture of the specimen using the D100. As we incrementally increased the stress load applied, we captured the variations in fringe patterns using the D100. After taking an image under the linear polariscope, we captured a corresponding image under the circular polariscope by simply attaching the quarter-wave plates. This process was repeated for both sets of specimen.

By holding our setup static for each image and only turning on and off the ambient (room) light, we ensured that our corresponding images for the linear and circular polariscope could be perfectly superimposed for subsequent analysis.

Crack Propagation using HSV.

We attempted to study crack propagations through plastic materials using the linear/circular polariscope setups previously described. We used as specimen, long rectangular sheets of acrylic plastic. After the specimen was inserted into the stress apparatus, we tried to manually capture crack propagations using the HSV, while manually trying to split the plastic sheet along the plane perpendicular to the plane of view.
MIT Spotlight Photo.

For a concluding part of our project, we decided to take aesthetic images using polycarbonate strips of plastic. We decided to cut out the letters "M" - "I" - "T" in a thin sheet of plastic and capture images of it under the circular polariscope, with the D100 camera. The letters were cut in the Hobby Shop using a band saw. Later the plastic was recut using the water jet, also in the Hobby shop, to produce cleaning images for the Spotlight.
RESULTS.

Figure 4: Three images of a strip with no notch with increasing stress. (Aperture - f/4, shutter sped - 320, lens - 50 mm, via our linear polariscope).
Figure 5: Three images of a strip with one notch with increasing stress. (Aperture - f/4, shutter speed - 320, lens - 50 mm, via our linear polariscope).
Figure 6: Three image of a strip with two notches with increased stress. (Aperture - f/4, shutter speed - 320, lens - 50 mm, via our linear polariscope).
Figure 7: Two images of a strip with no notch, as viewed through a circular polariscope and a linear polariscope, respectively. (Aperture - f/4, Shutter speed - 50, lightfield). (Aperture - f/4, Shutter speed - 25).
Figure 8: Two images of a strip with one notch, as viewed through a circular polariscope and a linear polariscope, respectively. (Aperture - f/4, Shutter speed - 50, lightfield). (Aperture - f/4, Shutter speed - 25).
Figure 9: Two images of a strip with two notches, as viewed through a circular polariscope and a linear polariscope, respectively. (Aperture - f/4, Shutter speed - 50, lightfield). (Aperture - f/4, Shutter speed - 25).
DISCUSSION.

This section is structured in the following way. In the first subsection Stress versus load, we discuss how and why the isoclinic and isochromatic fringes changed in our specimens when we increased stress on them. In the second subsection Isoclinic versus isochromatic, we describe an easy technique to isolate specimen’s isoclinic fringes from its isochromatic fringes, by using two images of the specimen, one from a linear polariscope and the second from the circular polariscope. In the third subsection Multiple notches, we discuss the predictability of stress patterns in strips with multiple notches, given the stress patterns for a strip with a single notch. In the fourth subsection Crack propagation, we discuss some known reasons for the failure of our crack propagation study. Finally, we conclude with some recommendations for future related studies.

Stress versus load. The images in RESULTS indicate that as stress on our specimens increased, the isoclinic fringes darkened. This result was completely expected, because, as mentioned in BACKGROUND, isoclinic fringes are bands, where each band represents a stress direction in the specimen. Thus, as the stress on the specimen increased, the strain in the specimen increased, and the stress directions in the specimen became more pronounced. More interesting observations were that, as the stress on our specimens increased, the isochromatic fringes became finer and the number of isochromatic fringes also increased. As mentioned in BACKGROUND, the isochromatic fringes occur at places where the phase difference is a multiple of \(2\pi\), that is, when the light components leaving the specimen along the slow and fast axes are in phase. Since the strain in a homogenous material is continuous, we saw the isochromatic fringes as black bands as opposed to black, line contours. As the stress on the specimen increased, the strain in the specimen increased. As a result, the change in phase difference over a same distance in the specimen also increased. Thus, the total number of isochromatic fringes increased since the total dimensions of the specimen remained the same. Also, because the bands of black were now thinner, the isochromatic fringes became finer.

Isoclinic versus isochromatic. As mentioned in BACKGROUND, we can use a linear polariscope to capture an image of the isochromatic and isoclinic fringes of a specimen, and we can use a circular polariscope to capture the same image of only the isochromatic fringes. However, we would really like to have a visualization of only the isoclinic images, because each isoclinic represents the positions in the specimen where the stress directions are the same. Thus, the isoclinic fringes gives us the general directions of the stresses in the specimen.

In order to visualize the isoclinic fringes, we took the images in Linear Polariscope versus Circular Polariscope in RESULTS, and processed them using Adobe Photoshop and MATLAB in the following manner. First, they were processed using Adobe Photoshop, by (1) changing their modes to grayscale, (2) blurring the image 5 times, and (3) each scaled to 50% its original size. Then, for every image from the linear polariscope, 'filename1,' and corresponding image from the circular polariscope, 'filename2,' a new .jpg file 'filename3' was created via the following MATLAB commands:

\[
\begin{align*}
&\text{>> } \text{LIN} = \text{imread}(\text{‘filename1’});
&\text{>> } \text{LIN}\_C = \text{imcomponent}(\text{LIN});
&\text{>> } \text{CIRC} = \text{imread}(\text{‘filename2’});
&\text{>> } \text{CIRC}\_C = \text{imcomponent}(\text{CIRC});
&\text{>> } \text{T} = \text{imlincomb}(-a, \text{LIN}\_C, -b, \text{CIRC}\_C);
&\text{>> } \text{imshow}(	ext{T});
&\text{>> } \text{imwrite(T, ‘filename3’, ’JPEG’)};
\end{align*}
\]

Via these MATLAB commands, we first imported an image from the linear polariscope and named it LIN. Then, we saved its complement image (the image were the black and whites are inverted) as LIN\_C. Similarly, we imported the corresponding image from the circular polariscope and named it CIRC and saved
its complement image as $\text{CIRC}_C$. Then, we saved a linear combination of $\text{LIN}_C$ and $\text{CIRC}_C$, in the form $-a\text{LIN}_C - b\text{CIRC}_C$, where $a$ is either $a = 1$ or $a = 0.9$, and $b = 1$. We named this linear combination $T$. Finally, we exported $T$ as a .jpg file named 'filename3.' The images below are the images from the linear polariscope, the circular polariscope, and their linear combinations (of their complements), of a strip of plastic with one notch, two notches, and three notches.

Figure 10: Super-positioning of isochromatic and isoclinic fringes in a strip with one notch, as seen via a linear polariscope.

Note that the black strips depicted in the above images are the isoclinic fringes minus the intersections of the isoclinic fringes and isochromatic fringes. On the other hand, the white strips depicted in the above images, are the areas where we do not have isoclinic fringes.
Figure 11: Isochromatic fringes in a strip with one notch, as seen via a circular polariscope.

Figure 12: Isoclinic fringes in a strip with one notch.
Figure 13: Super-positioning of isochromatic and isoclinic fringes in a strip with two notches, as seen via a linear polariscope.

Figure 14: Isochromatic fringes in a strip with two notches, as seen via a circular polariscope.
Figure 15: Isoclinic fringes in a strip with two notches.

Figure 16: Super-positioning of isochromatic and isoclinic fringes in a strip with three notches, as seen via a linear polariscope.
Figure 17: Isochromatic fringes in a strip with three notches, as seen via a circular polariscope.

Figure 18: Isoclinic fringes in a strip with three notches.
Multiple notches, etc. Another project goal was to study the stress patterns of multiple notches in strips to see if there weren’t enough repetition in the isoclinic and isochromatic patterns to predict the general contours of these fringes. By looking at the images in RESULT, we see that the isoclinic patterns do repeat and therefore, in theory, we should be able to predict the stress patterns of multiple notches provided that the distance between the notches are large enough, which makes perfect sense, since if there were infinite distance between consecutive notches, the patterns around each notch should be exactly those of a single notch on an infinitely long strip of plastic. Notice, however, that on our finite length strip with three notches, the isochromatic fringes around the middle notches are especially hard to see. This can be explained using our observations we made in the Stress versus load part of the DISCUSSION. That is, the strain around the middle notch is significantly (measurably) larger than the strain around the other two notches, and hence there are more isochromatic fringes around the middle notch, and these fringes are finer than those around the notches on the sides.

The study of crack propagation was unsuccessful because with the resources available to us we were unable to break the acrylic. This meant we did not have meaningful data available to be captured by the HSV. The plastic strips of polycarbonate were too elastic, the force was not great enough, and the intensity of the light source was too low for the study to go on.

With the elimination of these studies we were still able to capture many beautiful images. As a result of this we decided that it we could submit it to MIT spotlight with the intention of displaying MIT under stress. This involved the creation of plastic strips with the letters of MIT spelled out in notches and slits. Images taken with the D100 of the strips under stress gives the patterns of the cuts from MIT under stress. For final submission to the spotlight, we redesigned the MIT design and had them cut with the water jet machine at the hobby shop in order to have cleaner cuts. It will be available on the MIT homepages some time during Finals week. Figure 19 show the initial submissions for the MIT spotlight, while Figure 20 show the final submissions.

![Figure 19: MIT Spotlight Image 1.](image-url)
Figure 20: MIT Spotlight Image 2.

References