# Material Testing Fixture

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# Final Report

Document

Submitted towards partial fulfillment of the requirements for
***Mechanical Engineering Design – Spring 2013***

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## Contents

## Introduction

Our project is to design a new testing fixture for a Magnetic Shape Memory Alloy (MSMA). The current testing fixtures are causing fatigue failure in the specimens, which is undesirable. The new testing fixtures which we design will be installed on an Instron 8874 hydraulic bi-axial testing rig. These testing fixtures will operate in the presence of a magnetic field due to the nature of specimens. Because the specimens are extremely rare and expensive, axial alignment is one of the most critical components of this project. The project is to create a new fixture that is able to perform both tensile and compressive tests on the MSMA specimens.

## Background Research

Dr. Ciocanel has been involved in conducting research, along with the Chemistry department, in the field of Smart Materials. Specifically, Dr. Ciocanel has been looking into ways of storing electrical energy in carbon-fiber-based materials. If materials were embedded with electrical storage capacity, it could help industries to reduce weights and costs of manufacturing. Another area in which Dr. Ciocanel has been involved with is the use of Magnetic Shape Memory Allow. By conducting complex loading scenarios, Dr. Ciocanel can study the effects and properties of this material for future industry use. A key feature of the material is that it experiences up to 6 percent elongation when introduced to a magnetic field. The growth of the material also induces changes in magnetization, and voltage can be harnessed if a coil is placed around the specimen.

## Needs Identification

During our meeting with Dr. Ciocanel, he explained to us how the current testing fixtures caused unwanted eccentric loading of the specimens. This unwanted loading in the material is caused by misalignment of current testing rig. This misalignment causes fatigue cracks to form in the specimens, ultimately leading to catastrophic failure. These specimens are highly expensive and extremely rare, as they are only produced in two places around the world. The cost of each specimen is roughly $1,000, and it can take up to one year to grow the specimen. This fixture is also slightly larger than the specimen, which allows the specimen to move when the magnetic field is introduced. Dr. Ciocanel expressed the need for a new testing that will not cause the specimen to prematurely break. Dr. Ciocanel also expressed an interest in a testing fixture that would be able to perform compression and tension tests. The current fixture design only allows for compression testing.

## Project Goal and Scope of Project

The goal of our project is to create a new testing fixture that is capable of performing tension and compression tests on magnetic shape memory alloy. This goal includes being able to repeatedly test specimens without causing them to fatigue and break prematurely. We are limiting the scope of our project to the small scale testing performed by the Instron 8874 hydraulic bi-axial testing rig.

## Objectives

In our project there are four main objectives. First, the connection between the pushrods and base need to be axial aligned. If this connection is not aligned, the eccentric loading will cause the specimen to break. Second, the new fixture must be able to perform both compression and tension tests. Third, it is imperative that the new fixture not damage the specimen. The cost and rarity of the material make this objective of great importance. Finally, the new design should be as inexpensive as possible without sacrificing any of our objectives. Below in Table 1, our objectives and basis for measurement are shown.

**Table 1: Objectives**

| Objective | Basis for Measurement | Units |
|---|---|---|
| Axial Alignment | Distance from perfect axial alignment | µm |
| Tension/Compression Tests | Repeated Testing | # of Tests |
| Does not damage material | Cost of new specimen / Time for replacement | $$ / Months |
| Inexpensive | Cost to machine and purchase material | $$ |

## Constraints

For the new testing fixture, there are seven constraints that the new design must meet. These criteria are listed below with a short description of each.

1. **Axial alignment:** It is crucial that the specimen be axially loaded.
2. **Pushrods and grips must be non-magnetic:** The magnetic field of the pushrod must not interfere with the applied magnetic field.
3. **The distance between magnetic poles:** The distance between the magnetic poles is limited to 10mm.
4. **Exposed length of the specimen:** Thee must be at least 6mm of the specimen for the camera to monitor.
5. **Specimen size:** The base of the specimen is slight variation, and the size is normal 20mm long with a 3 x3 mm cross sectional area.
6. **Safety of the specimen:** The fixture cannot bite into the specimen causing damage.
7. **Magnetic field:** The applied magnetic field varies form 0.5~1 Tesla (T).

## Concept Generation

### Clamp Tip

This design consists of a redesigned pushrod, four independent clamping components, screw adjustable tension clamp, and a rubber insert. The unique feature of the clamp tip is the screw guided clamping components which are controlled by the tension clamp. This design is user friendly and allows for easy one screw adjustment while also maintaining axial alignment. In the center of the four clamping components is a rubber insert or rubber coating to ensure that the specimen remains undamaged while conducting tension testing. Below in Figure 1, a model of this design is shown.

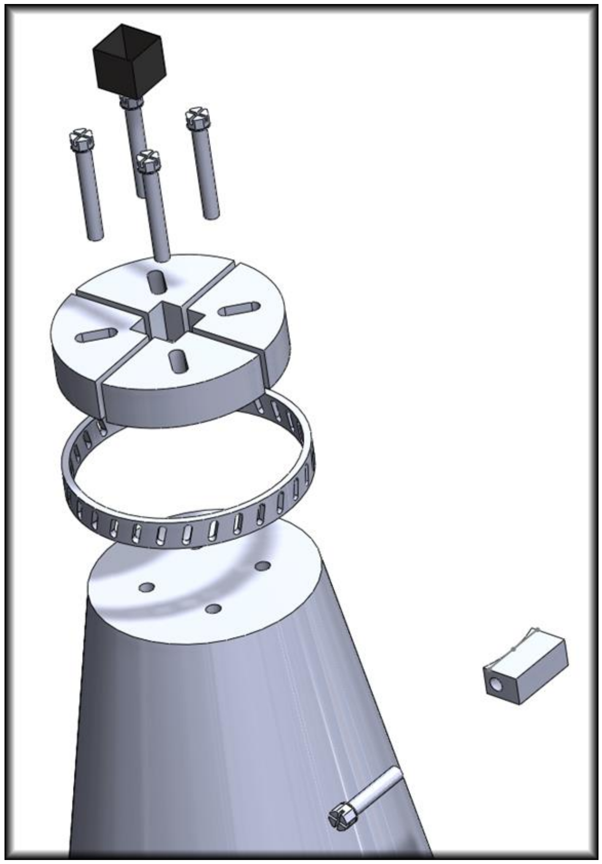

**Figure 1 –** Clamp Tip

**Screw Tip Design**

The goal of the screw tip design is to ensure the axial alignment of the specimen by using four set screws to control the alignment of the specimen. This design also allows for the specimen to be tested in tension. In order to make the design not damage the specimen, a rubber insert is placed between the screw ends and the specimen. This design however will require a lot of adjustment each time a specimen is tested. Below in Figure 2, a model of this design is shown.

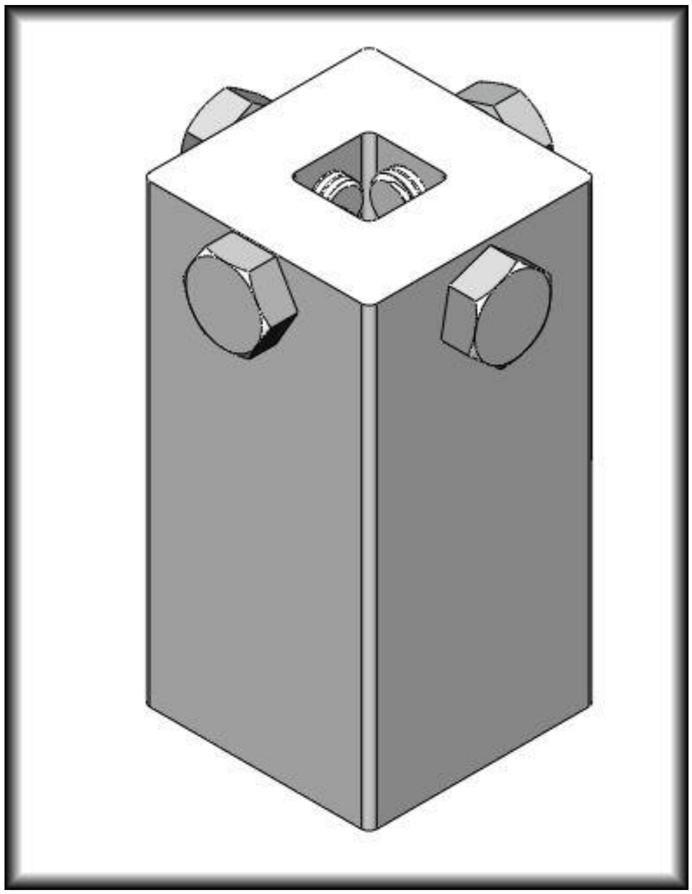

**Figure 2 –** Screw Tip

**Adjustable Base**

In this design there are 4 adjustment screws that press on the force analyzer to align the tip that hold the specimen. The problem with this design is that while it corrects the alignment of the specimen, it transfers the misalignment to the force analyzer. This simply shifts the location of the problem rather than fixing the design. Below in Figure 3, a model of this design is shown.

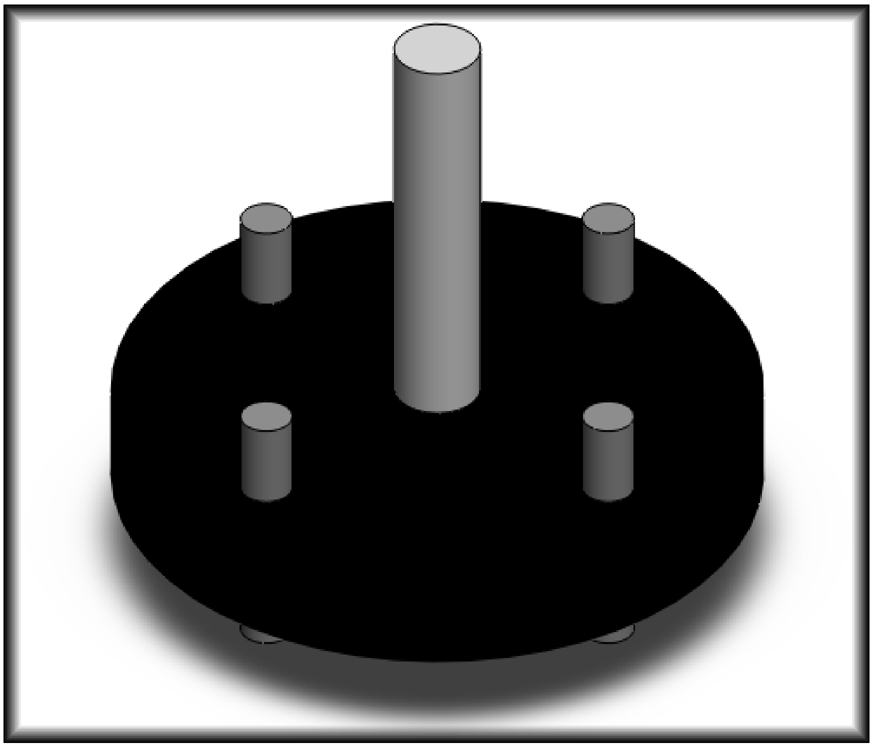

**Figure 3 –** Adjustable Base

**Base Sleeve**

This design is comprised of four main components. They are the pushrod, sleeve, force analyzer and securing screw. First the pushrod is inserted into the sleeve. Then the sleeve and pushrod are inserted into the force analyzer. Next, a screw will be used to secure sleeve and the pushrod. This design has three main characteristics. First, in order to keep the connection between the pushrod and base perfectly aligned, the sleeve will be made as large as possible. This large base will ensure that the pushrod is stable. Second, in order to ensure axial alignment, the tolerance between pushrod and sleeve will about 50μm.

Finally, because there is only one screw, this design requires very little adjustment. Below in Figure 4, a model of the base sleeve is shown.

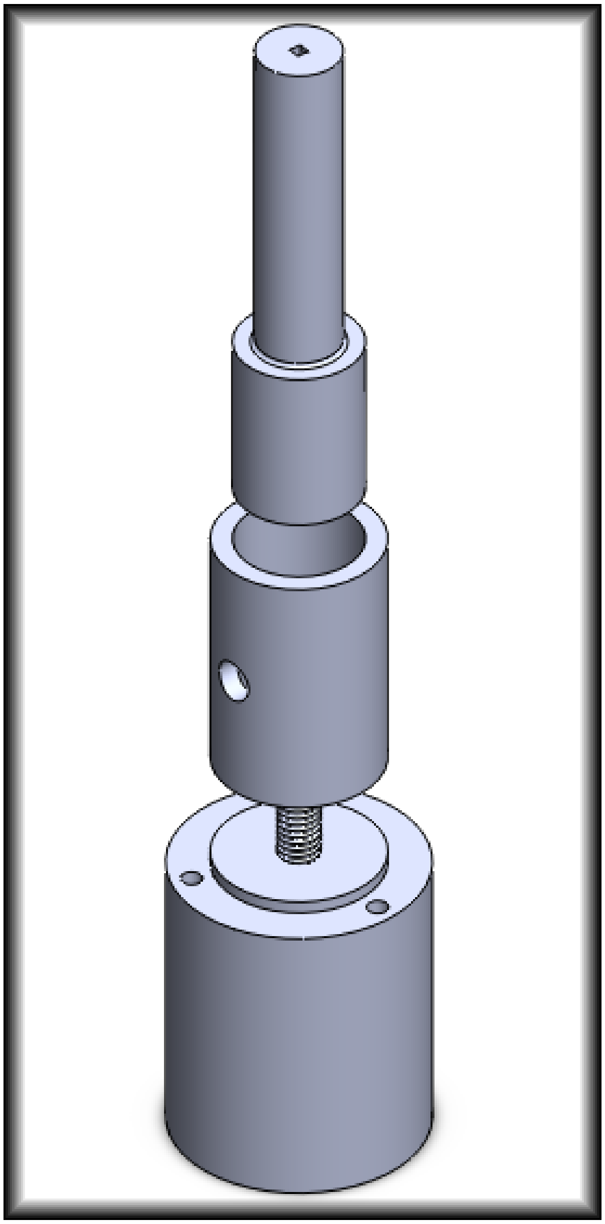

**Figure 4 –** Base Sleeve

**Collar Base**

This design is comprised of four main parts. They are the pushrod, collar, force analyzer, and four screws. Using the existing screw holes on the force analyzer, the screw holes are extended and tapped out. Then using the tapped out screw holes, the collar will be secured to the force analyzer. This will ensure the axial alignment of the pushrod. Then the pushrod will be inserted in the center hole of collar, and a set screw will be used to secure the pushrod to the collar. This design will ensure that the pushrods are axially aligned and there is no extra horizontal force applied to the force analyzer or specimen. This collar will ensure that the bottom of the pushrod and the force analyzer sensor are perfectly aligned. This sensor is used to collect data for the compression force. Finally, the tolerance between the center hole of the collar and the pushrod will also be machined to about 50μm to provide the perfect axial alignment. Below in Figure 5, a model of the collar base is shown.

**Figure 5 – C**ollar Base

**Updated Design**

The updated pushrod design is based off the former design known as the screw tip. For this design we eliminated the four independent clamping components and elected to use a single screw to secure the specimen during testing. This new design significantly reduced the tip size which ensures that the tip does not interfere with the 10 mm distance between the magnets. This was one of the problems with the previous designs. The new design is also easy to adjust, utilizing one screw to secure the specimen within the tip of the pushrod.  Below in Figure 6 a model of the new design is shown.

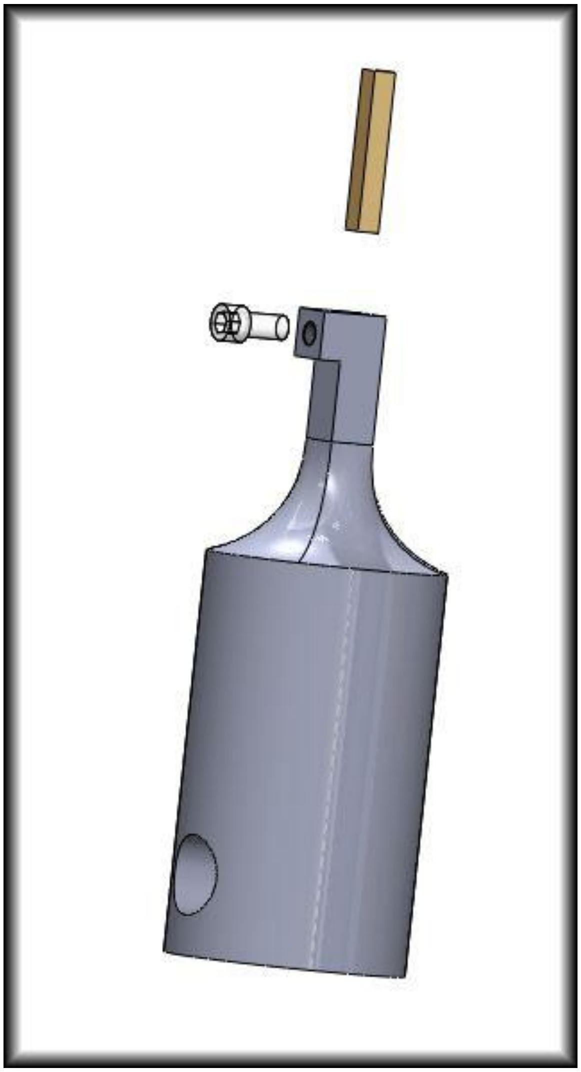

**Figure 6 –** Updated Design

## Concept Selection

In this section we will discuss the decision making process and the methods used in selected an initial design. The first aspect of the concept selection process was to weigh our goals and objectives. In order to do this we created a table to help us choose between our designs. Below in Table 2, is a table that rates the importance of our objectives to a scale from 1 to 9.

**Table 2: Analytical Hierarchy**

| Judgment of Importance | Numerical Rating |
|---|---|
| **Extremely Important** | 9 |
| | 8 |
| **Very Important** | 7 |
| | 6 |
| **Strongly Important** | 5 |
| | 4 |
| **Moderately Important** | 3 |
| | 2 |
| **Equally Important** | 1 |

As seen in the table above, this rating is on a scale of 1 to 9 in order of equally important to extremely important. Using this criteria we can then make a judgment of how importance of each objective. To do this we created a matrix and assigned values to each of our objectives. Below in Table 3, the values and the corresponding objectives are shown.

**Table 3: Weighted Objectives**

| | |
|---|---|
| **Axial Alignment** | 9 |
| **Tension & Compression** | 5 |
| **Damage To Specimen** | 9 |
| **Inexpensive** | 4 |

As can be seen from this table, “Axial Alignment”, and “Damage To Specimen” are critical. The axial alignment is crucial because the eccentric loading of the test specimen is causing crack propagation. This ultimately leads to the catastrophic failure of the test specimen. Because of the rarity of the specimens it is crucial that the specimens not be damaged. For this reason, “Damage To Specimen” is rated as extremely important.

Although not a primary objective of this project, we would also like to design the new fixture to be able to perform tension tests which are currently not supported. For this reason the objective “Tension & Compression” was given a rating of 5, which corresponds to “Strongly Important.”

Finally, we would like to make the new fixture as inexpensively as possible without compromising any of our objectives. Thus, the objective “Inexpensive” was given a rating of 4, which corresponds to slightly more than “Moderately Important.”

To proceed with the selection process another scale was created that relates how closely our designs match our objectives. Below in Table 4, this scale is shown. The values range from 1, meaning the design does not meet objective, to 5, meaning that the design meets the objective extremely well.

**Table 4: Objective Matching Scale**

| Meets Objective | Numerical Rating |
|---|---|
| Extremely Well | 5 |
| Very Well | 4 |
| Well | 3 |
| Not Well | 2 |
| Not At All | 1 |

Next, all of these criteria are substituted into a large decision matrix. Below in Table 5, each of the designs is matched to our objectives and then weighted. The weighted total is calculated and shown at the bottom of the matrix.

**Table 5: Decision Matrix**

| | Tip | | Base | | | |
|---|---|---|---|---|---|---|
| **Objectives** | **Clamp Tip** | **Set Screw Tip** | **Adjustable Base** | **Base Sleeve** | **Collar Base** | **Objective Weight** |
| **Axial Alignment** | 5 | 2 | 1 | 4 | 5 | 9 |
| **Tension & Compression** | 4 | 4 | 3 | 3 | 4 | 5 |
| **Damage To Specimen** | 4 | 4 | N/A | N/A | N/A | 9 |
| **Inexpensive** | 2 | 4 | 4 | 3 | 2 | 4 |
| **Total** | 15 | 14 | 8 | 10 | 11 | |
| **Weighted Total** | 109 | 90 | 40 | 63 | 73 | |

According to the decision matrix and our ranking scales, we decided that for our initial design, we will proceed with the Clamp Tip and Collar Base.

## Final Design

The final design featured several key parts. First, the tip has four individual tines, which allow for the specimen to be uniformly secured from all sides. The tip is attached to the push rod, which was shortened in length from the original push rods. A close-up of the tip can be seen below in Figure 7.

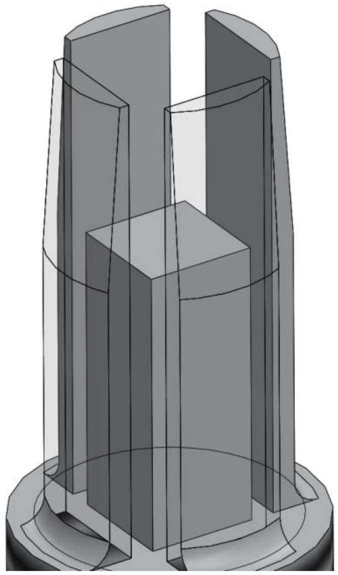

**Figure 7 –** Tip

The bottom push rod has a circular cut out on the bottom, which allows for the bottom push rod to rest on the top of the load cell. It has a cutout through the center of the push rod to allow a micrometer device to be inserted and used during testing. A close-up of the bottom push rod can be seen below in Figure 8.

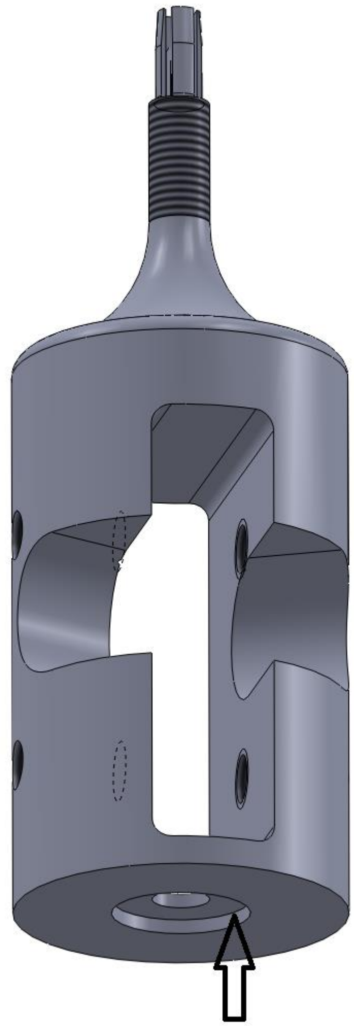

**Figure 8 –** Lower push rod

The top push rod has a circular extrusion, which is meant to fit into a circular cut into the top load cell. It has a similar construction to the lower push rod, but does not have a cutout for a micrometer. In Figure 9, the upper push rod is shown.

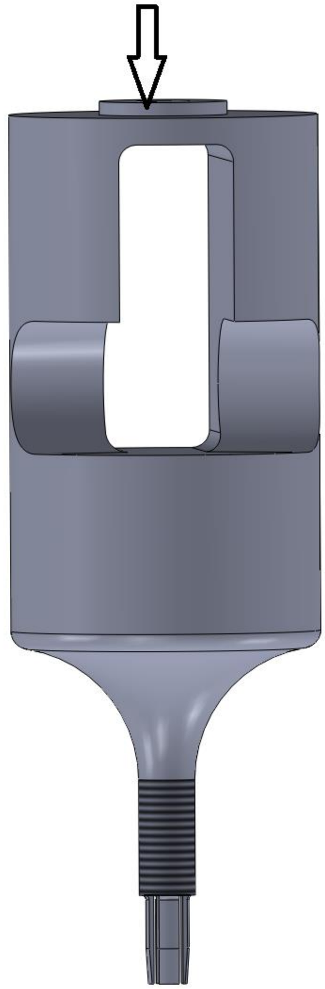

**Figure 9** – Upper push rod

Each push rod requires a sleeve to be screwed on in order to secure the specimen. The sleeve has threads on the inside, and a tapered section on the top. As the sleeve is screwed on, the tines are forced to close on the specimen, securing it in place. A cross sectional view of the sleeve can be seen below in Figure 10.

**Figure 10** – Sectioned Sleeve

## Prototyping

In order to create some of prototypes for this project it was necessary to use a rapid prototyping process. The processes and machines were made available to us by Dr. John Tester who is in charge of the Rapid Prototyping Lab at Northern Arizona University. With his aid we were able to take the Solidworks drawings and create physical models of our parts.

It was also necessary to produce one of our parts using the Machine Shop. After creating Solidworks drawings, we converted the drawings to G-Code in order to operate the CNC machines.

**Sleeve**

The sleeve prototype was made using a prototyping process that sprays on the material. After each pass that the machine makes an ultraviolet light cures the liquid material. After it hardens, the part is ready to be used. Because of this process, we were able to model thread patterns in

Solidworks and have the machine produce the threads. Two prototypes were created using this machine, but with different tolerances. The sleeve with less accuracy actually fit the tip prototype better than the sleeve with more accuracy. This was due to the fact that the sleeve with higher accuracy had too tight of tolerances when meshed with the collet prototype. In Figure 11, the thread pattern that was printed can be seen quite clearly.

**Figure 11** – Sleeve Prototypes

As stated earlier, there were two different sleeves that were modeled. In Figure 12, the two different sleeves are shown.

**Figure 12** – The left sleeve has tighter tolerances than the right sleeve

The sleeves contain a slight taper at the top, which, when screwed onto the tip, causes the four tines to close in around the specimen, securing it in place.

**Collet**

The collet was also produced with spray-on rapid prototyping process. It was done this way because the threads could be accurately reproduced. In Figure 13, the collet is shown in comparison to a standard 0.5mm pencil.

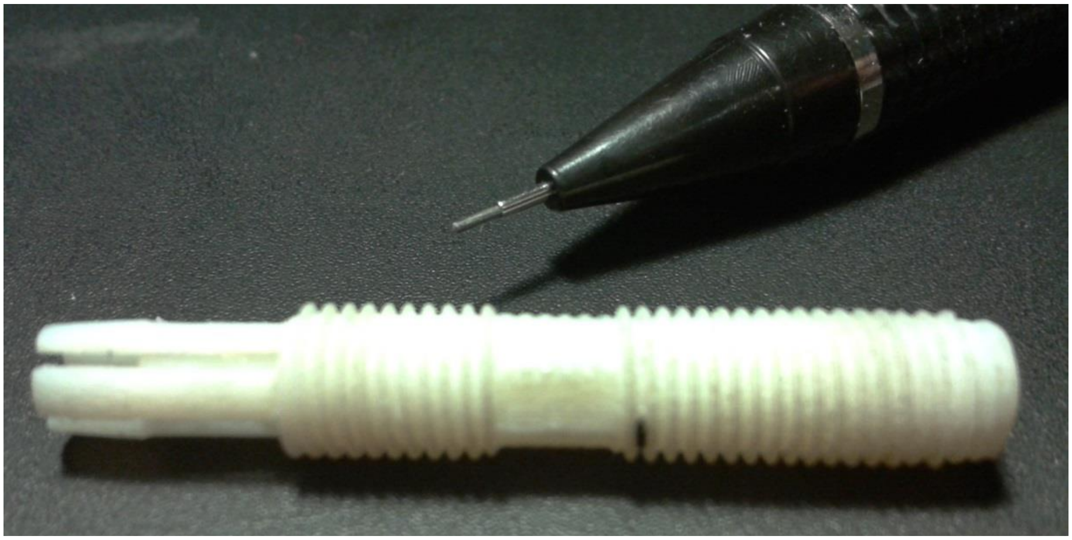

**Figure 13** – Collet compared to a 0.5mm pencil

Here the threads of the tip can be seen. Also the tines which hold the specimen and even the slight taper are visible. For prototyping purposes the collet and base were created as two separate parts. This is because the cost of producing the smaller parts was much greater than using the less accurate Fortus FDM machine. There was also less material available to print with the accurate machine which meant that only the parts with the highest tolerances would be produced. This is not representative of the final product, which will be produced as a single part. The base and the collet will be machined out of one piece of Stainless Steel 316. The reason for this is that the alignment of a single part will be much easier to maintain rather than producing two separate parts.

Once the sleeve and collet had been produced it was time to see how the two parts were mated. In Figure 14, the assembly of the sleeve, collet and specimen is shown.

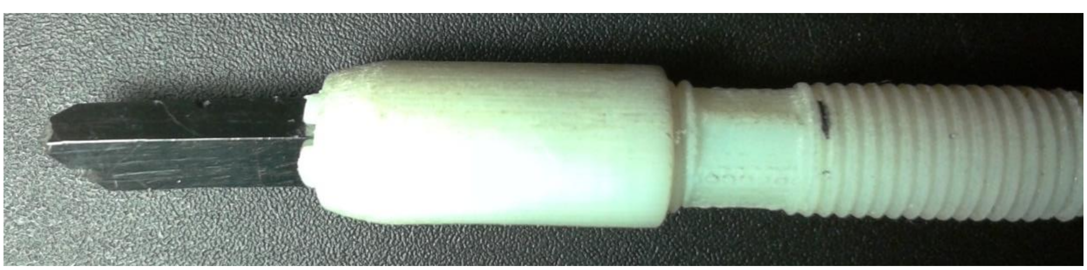

**Figure 14** – Collet assembly

The mating of the collet and sleeve were quite accurate. Using the loose tolerance sleeve we were able to mate the sleeve and collet, while securing the specimen inside. The force that was exerted on the specimen was enough to keep the specimen in place during light tension; however, if too much force was applied the specimen would come free. This proved that the collet concept will meet the requirements of the project with a few modifications.

**Base**

The lower base design is a round cylinder that is large compared to tip. On the top of the base, there is a thread hole that was created for prototyping that allows the tip to screw into the base. This threaded part is purely modification for the prototyping, as the final product will be made from a single piece of steel as mentioned earlier. In Figure 15, the top of the base can be seen with the threaded hole. In Figure 16, the right side of the base is shown. Here the two holes for securing the micrometer can be seen. Also the round cutouts at the bottom of the base are there to allow an allen wrench to secure the base to the force analyzer.

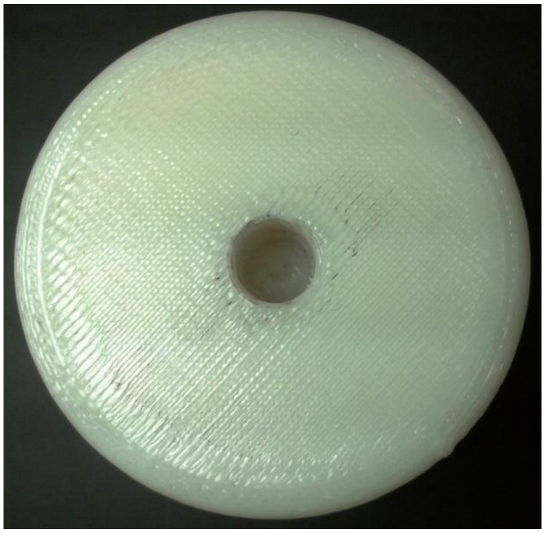

**Figure 15** – Top of base

**Figure 16** – Right Side

In order to secure the base to force analyzer a small round cutout is place in the bottom of the base. This will be used to secure the base with the force analyzer and provide the axial alignment. In Figure 17, the cutout can be seen. There are also cutouts in the center of the base that allows the micrometer to be positioned; this is shown in Figure 18.

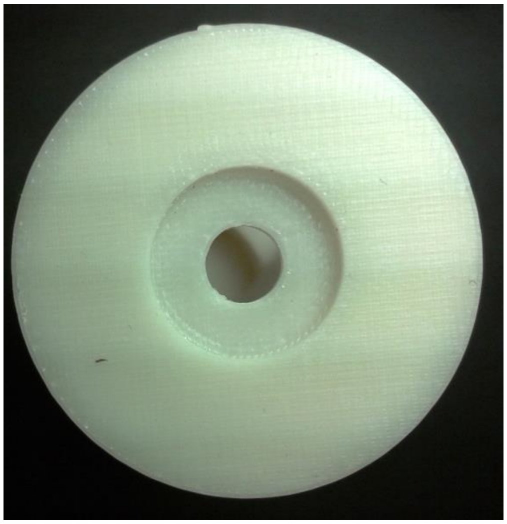

**Figure 17** – Bottom view

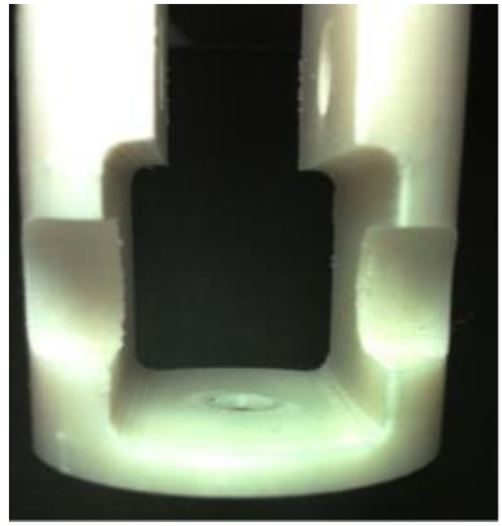

**Figure 18** – Front view

**Micrometer Tip**

One addition to the project is that we needed to be able to apply lateral loads onto the specimen. In order to do this, we needed to create new micrometer tips. These tips will fit over the micrometer and allow lateral forces to be applied. We have several material choices for the tips which include; aluminum, copper and titanium. We decide to use aluminum because it is relatively easy to machine, and readily available. Because the lateral forces which are applied to specimen are so small, the yield strength of the material is not a high priority and the aluminum meets these requirements adequately. For the tip design, we implemented a simple design shown in Figure 19, to reduce the amount of machining time that it would require.

**Figure 19** – Micrometer tips

The design of two tips are mostly the same, however, there is slight difference is at the bottom of the tips. One has a big hole which will be connected with the micrometer tip directly, while the other has a small threaded hole which allows a force sensor to be attached. This sensor allows the lab technician to collect and store data on the poisons ratio change as the magnetic field is applied. After considering manufacturing procedure and the material, we decide to use a CNC mill to produce the tips. First, we built up the model of micrometer tip in the Solidworks, and then we modified the manufacturing procedure in CAMWorks to output the G-Code which runs the mill. Finally, using the SuperMax CNC machine and the assistance of the lab technician, the parts were fabricated. In order to understand the role that the tips play in applying the lateral force an image of the tip assembly is shown in Figure 20.

**Figure 20** – Lateral Assembly

Finally, in order to ensure that the tips will not damage the specimen, a very thin silicon rubber sleeve will be attached to the area which contacts the specimen.

## Final Product

The final design, as shown in Figure 21, was manufactured in California using Electro Discharge Machining, or EDM. This process removes material by discharging a current between an electrode and the material. Each time the electrodes arc, a small amount of material is removed from the part.

This process allows for very high tolerances, and extreme accuracy. By using this process, small dimensions and tolerances were easily achieved.

**Figure 21 –** Base Push Rod

The base push rod fit very well into the testing fixture. However, the top push rod did not fit into the top of the testing fixture. Unfortunately, we had incorrectly measured the diameter of the center of the mounting fixture. A visual of the incorrect dimensions can be seen in Figure 22.

**Figure 22 –** Top Push Rod

In order to compensate for the top push rod being too small when compared to the mounting fixture, we decided to machine a washer, with the correct dimensions, and press-fit them to the top push rod so it fits into the mounting fixture correctly. Below, in Figure 23, the push rods with the press-fit washer can be seen.

**Figure 23 –** Press fit washer

After the top push rod was corrected with a press-fitted washer, small silicon linings were cut in the general shape of the specimen. These silicon sleeves will wrap around the specimen as it is inserted into the push rod, in order to prevent damage to the specimen, as well as aid in tension testing. Below, in Figure 24, a close up of the specimen inserted into the push rod, while wrapped in the silicon sleeve can be seen.

**Figure 24 –** Silicon Sleeve

Finally, both the top and bottom push rods were mounted in the testing fixture. One installed, the machine as adjusted, and the result can be seen below in Figure 25.

**Figure 25** – Full assembly

## Material Selection

In this section we will discuss the materials that are involved in this project. There are three main categories of material that are required for this project: Pushrod/Sleeve, rubber sleeve, and screws.

### Push rod and Sleeve

For the push rod and sleeve which are the main components of our design, our previous decision was to use the Aluminum Alloy 6061 – T6. Although the yield strength of the aluminum alloy (240MPa) met our requirements we decided to look into a more durable material that could better withstand repeated testing. After looking at several different materials, we decide to use Stainless Steel 316CR. It has greater yield strength (410Mpa) than the aluminum alloy and will be much more durable. Because the stainless steel has a higher modulus of rigidity than aluminum, many of the variations that would be present in aluminum will not be seen. This will help improve axial alignment, by decreasing the variations that would be found in the aluminum. Most importantly the Stainless Steel 316CR is a diamagnetic material.

Although the diameter of the pushrod was chosen to be 35mm, we decide to use a round bar which has a diameter of 40 mm. This will allow for a small buffer when machining the parts. Considering waste and manufacture procedure, the length of the bar we will use is longer than the exact length of the push rod which is 300mm. This will also account for the creation of the collet sleeves. After searching online, we found that this amount of material could be bought for approximately $50 USD.

The team was concerned about the tines and the stresses experienced at the base due to the bending of each tine to secure the specimen during testing. We then proceeded with hand calculations of the bending of each tine, modeling the tine as a beam with an applied load at the tip. After assuming a stress concentrator of 3 at the base of the tine and completing the calculations, the results yielded indicated the specimen would fail due the stiffness of the material. Initially we had elected to use the stainless steel because of the hardness of the material and its ability to withstand deflections on the micrometer level. However due to the stiffness of the material the deflection required to secure the specimen during testing would cause the tines to fail. Once again we began searching for materials with capabilities necessary to meet the requirements for the testing application. We tried several materials, basic and exotic materials; the exotic materials performed better and ensured longer life of the tines. The standard materials performed average, with some failing and others just barely surviving the great amounts of stress generated. We chose Aluminum 7075 - T6 due to the relatively low cost of the material and the workability of the material while remaining relatively stiff and allowing very little deflection when loaded.

**Rubber Sleeve**

Because the specimen is not always guaranteed to be square, we must ensure that the specimen is in perfect axial alignment regardless of the dimensions. To do this we will use silicon rubber sleeve on the tips of the push rod. This way, when the sleeve is tightened around the specimen, the silicon rubber can compress so as to accommodate varying specimens. The reason we choose silicon rubber sleeve is because we wanted a very thin rubber sleeve, 0.1mm, with good compressive properties.

Because the tip of the push rod is the only part of the fixture that needs these sleeves, we only require a very small amount of the material. The total amount will be less than (200 x 200 x 0.1)mm, and will cost approximately $3 USD.

### Screws

There are four screws that go through the push rod to secure the micrometer. We choose the socket set screw (SSS) with dimensions 5/16-18 UNC. The screws are threaded along their entire length with nominal thread diameter of 0.3125 inches. For this project, we will need the screws to be at least 10mm. The screws are unified coarse and machined in black oxide that provides protection against corrosion

## Analysis

For the analysis, it was necessary to focus on the most critical aspects of the design. This is seen in the pushrod and the tines.

### Push Rod

In order to secure the push rods to the force analyzer slots will need to be cut into the pushrod. Because of this, it is important to know how these slots will affect the integrity of the material. We performed an analysis on the base of the bottom pushrod where the area of the push rod would be the smallest. In this area a portion of the rod would be cut in order to accommodate an allen wrench which would be used to secure the pushrod to the base of the testing fixture. The idea with this is to tighten the pushrod down and utilize the concentric surface of the load cell to achieve axial alignment. Below in Figure 26, a graph that shows the relationship between stress and diameter is shown.

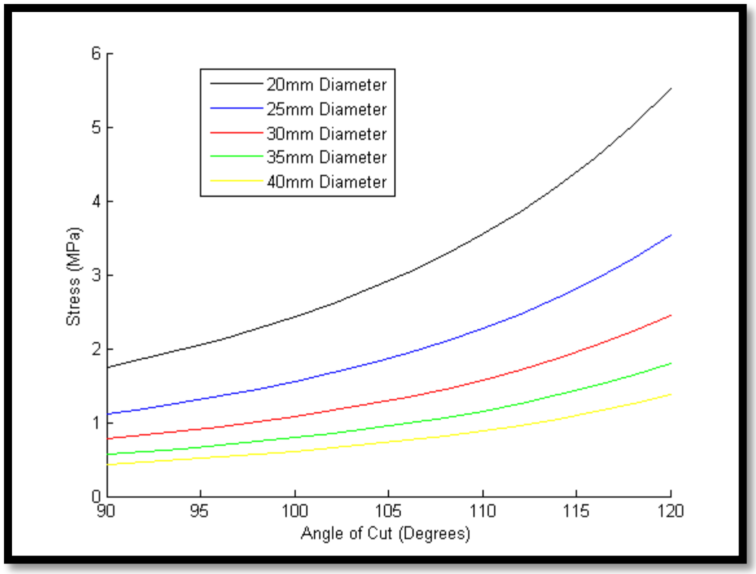


**Figure 26 –** Stress vs. Angle

As can be seen from this data, the stresses involved at the cut out portions of the push rod are negligible. This is due to the small load that is seen on the push rod itself. The angle of cut is similar to pie shaped cut made from 90-120 degrees and the stress is the force place on the remaining area of the diameter. This analysis was carried out for varying diameters ranging from 20mm to 40mm. As the diameter decreases the stress increases. Below in equation **(1)**, the equation for calculating stress is shown.

When the final design had been chosen, we were able to perform an analysis on the tines, which are the most critical parts of the design. Using SolidWorks Simulation Xpress, and COSMOS, the stresses in the tines were calculated and compared. In Figure 27 and Figure28, the analyses are shown. It can be seen that both SolidWorks and COSMOS yield a maximum Von Mises stress of nearly 143.0 MPa, which is well below the yield strength of aluminum 7075 – T6.

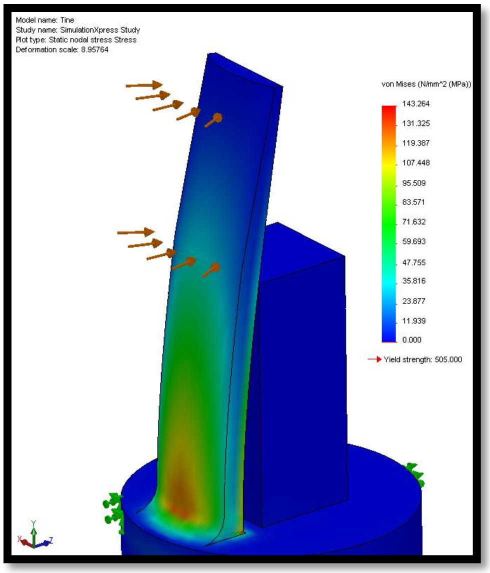


**Figure 27** – SolidWorks Tine Analysis

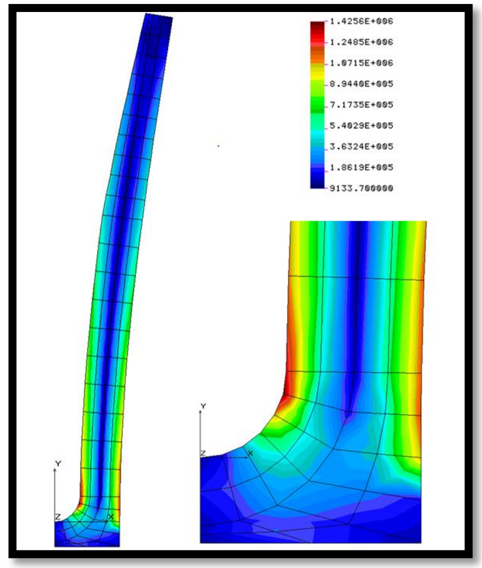


**Figure 28** – COSMOS Tine Analysis

## Conclusion

The new fixture improves the axial alignment of the testing rig by using coradial alignment. This new design has also reduced the number of parts, which reduces accumulation of error from tolerance stacking.

Each of these improvements has led to a design that is axially aligned, reliable and capable of performing tension and compression tests. Our client, Dr. Ciocanel is extremely pleased the outcome of the final product, and he looks forward to using it in his research.

By using the testing rig for axial alignment, rather than relying on screws, we have greatly improved the alignment of the specimen in the testing rig. This allows for more accurate data to be collected.

The collet style fixture that was designed as the solution ensuring the specimen will be axially aligned by applying equal force on all sides of the specimen during testing. A silicon sleeve was incorporated in the design to compensate for any size variation in the specimen, as well as ensure that there is no damage to the specimen.

Although the new design help improves the axial alignment during the duration of the testing, the way the upper component was intended to be used was not completed successfully. Due to time constraints and travel time, we determined a specific date at which the parts must be in the teams possession. Supplying the manufacturing company with drawings and specifications a week prior to their departure from the manufacturing site was critical to receiving the parts on the date specified. As a result of the time constraints the dimensions were not confirmed. The diameter of the upper component base where it mates with the Instron loading cell, is an extruded diameter, when fitted correctly increases the chances of achieving axial alignment. The diameter specified was smaller than opening. We were able to correct this error by producing two copper washers to serve at spacer. These washers were then press fitted on the fixture and the component is now able to function as originally intended.

We have met the requirements of maintaining an exposed specimen length of at least 12 mm to be observed by a camera, allowing for variable specimen size, and accommodating for both compression and tension testing.

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