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Tabletop Dome Tester

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Senior Honors Project Report

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Abstract

The project for the dome tester stand is a continuation from a group of four that worked on the stand in Spring of 2020. The project itself is based around the Erichsen Cupping test to test the material properties, in our application specifically, observing the forming limits of strain in deep drawing applications of sheet metal. Testing pieces in varying lengths from 4” x 4” squares to 4” x 0.5” strips to the depth that necking begins on the piece to determine the limit before cracks appear using a hemispherical punch to draw the material sample clamped between two dies. The main goal of this project was to understand what all is necessary to test these materials properly and to create a process that will be able to provide future students with the hands-on opportunity to test materials and formulate forming limit diagrams for various materials on their own at The University of Akron.

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Introduction

Background

The testing being completed on our specimens come from a similar background and procedure of what is known as the "Erichsen Cupping Test". The principal of the Erichsen Cupping Test is very simplistic in theory as a hemispherical punch is used to punch into sheet metal until a crack appears and once that occurs the depth of the cup is measured. In the sense for the Dome Testing Stand, the process is the same, but measurements are differing as the procedure looks to take the material until it begins to neck instead of taking it to full fracture. Ignoring the depth of the material punched and analyzing the major and minor strains that are displayed near the necking area, the data can be used to create a broad view on the formability of the respected material. The Erichsen Cupping Test aims to test for the ductility of the samples, while the dome testing stand looks to determine the Forming Limit Diagram of the samples to help with future design of deep drawing applications with the material.

There are many factors of metal sheets that affect the formability of the material, such of those being the hardness, ductility, grain direction, and surface roughness. Metal forming aims to create products with high strength to hold its shape, but as the strength of the material is increased the ductility of the material accordingly is worsened making it harder to manufacture more complex pieces with such specified material. Two of the largest factors of formability are of these characteristics and can be reflected by shifts in the Forming Limit Diagram for materials with differing yield strengths and ductility. [8]

Deep drawing is a process in which complex products are formed by drawing in sheet metal blanks into a hollow cavity, also known as a die, using force from the punch. Blank holders are used to control the flow of the metal material into the die to reduce the stresses. There are many cases of failure in deep drawing such as insufficient friction between the blank and punch, wrinkling on the wall due to insufficient clearance between the die and punch surfaces, tearing occurs when the metal is pulled over a sharp corner on the die, and wrinkling on the flange due to compressive buckling on the flange that is not being drawn are among the most common. These are amongst the main issues to avoid in designing the Dome Tester Stand to perform these Erichsen Cupping Tests. To determine the limits of forming during these deep drawing processes, Forming Limit Diagrams are used to aid in the design process, determining the manufacturability of different forms depending on the materials used. In the industry it is used primarily in drawing applications to ensure the design of products meet the satisfactory requirements. This is what the Dome Testing Stand is looking to provide to students, the opportunity to hands on determine the forming limits of materials so that it may be understood better by the students.

Using etched grids of circles on materials, strains around the necking area can be determined using calibrated Mylar^{TM} strips that are used to translate the changes in circle shapes on the grid to percent changes of strain in the major and minor directions. [1] Using data collected from the circles located near the necking area of the material blank, the major and minor strains can be identified and plotted for various sized blanks to paint the Forming limit curve of that material to be able to quantify the limits that the material may be formed to. The limit changes as both the major and minor strains change, the minor strain can only be positive as the circles turn to ellipses, and the major strain can either be a positive or negative value on our plot since the material is being stretched in at least one direction, and not being fully compressed in both directions. [7] The circle grid method of analysis for forming limit diagrams presents a very cost-effective procedure to show results but at the cost of slower analysis and more potential for error.

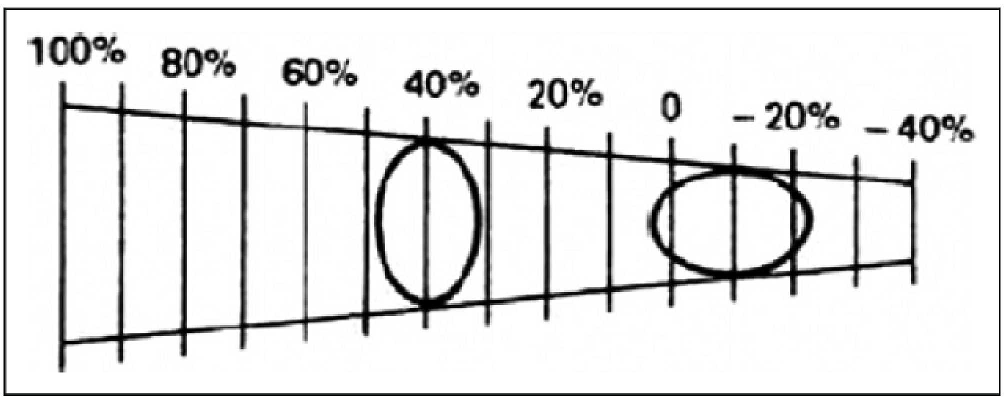


Figure 1: Strain Scale example on our Mylar^{TM} Strips

To improve upon the accuracy and effectiveness of the analysis of the strain at necking of materials, Digital Image Correlation (DIC) is another method that uses camera-based equipment to more accurately decipher changes in patterns etched onto the material but at a much higher cost. Using the circle grid method for the Dome Testing Stand shows to be the more effective option to provide students the ability to be experience a hands-on demonstration of deep drawing and the application of the forming limit curve. DIC is a resource that can be utilized to help verify the accuracy of the lower cost procedure for the Dome Testing Stand.

Design

Previous Design

Previously designed were the initial punch and dies to be machined for the use of testing materials for their Forming Limit Diagrams. The dies are 10” x 10” x 1” each, with eight evenly spaced through holes arranged in a circle of diameter 6.5” allowing for even clamping of the material piece that allows up to a 4” x 4” samples between the bolt spacing. There lies a 1/8” clearance between the punch outer diameter and the bottom die inner diameter surfaces which allows us to test up to a material thickness of 80%-90% of that clearance based on industry standards for deep drawing. A hydraulic press was chosen by this previous team to stay within their very minimal budget that was set and to still provide the necessary punch force to form very strong pieces of material. Eight ½-13 Grade 8 bolts were selected per A354 BD by this team as well, because they were capable of a maximum clamping force of up to 7.1955 tons per bolt and were specified to be torqued to 34° past hand tight, which is a very vague reference to the torque that should be applied to evenly distribute the force across the blank holder. To determine a more concrete value of the bolt torque specification, further calculations were made to determine a torque value or accuracy instead of a rotation of the bolt off an unreliable state of “hand tight”

Bolt Calculation Fix

Following initial testing there was seen a need to fix the hold down force that was exerted by the bolts onto the top die downward clamping the material sample. Each test exhibited signs of wrinkling on the flange that can be seen in *Figure 12, Figure 13,* and *Figure 14,* which is the result of too little of force holding down the sample properly. Previous bolt torques were calculated from a forming force of a different type of material sample not taking into effect the material properties of the HDG Deep Drawing Steel that were being tested currently, as well as providing a value of angle of rotation to reach that is difficult to physically exhibit instead of a numerical torque value that can be provided by a torque wrench. With initial testing results of our blanks, there was very prominent wrinkle deformation of the flange area which displays insufficient clamping force using the previous specification provoking a search into a different computation for bolt torque. Instead of looking to the bolts themselves and how much they need turned, using the hold down pressure that has been optimized though Finite Element Analysis (FEA) found in an International Engineering Research Journal [6] for deep drawing steels and the area that must be held down, we can compute a value that can more easily be expressed accurately on the stand.

Using **Equation 1:** $Blank\ Holder\ Force = Holding\ Pressure\ x\ Holding\ Area$, where *holding area* is the area outside the diameter of the punch, and *holding pressure* is the given value from the material properties table located in *Table 1* we can compute the proper holding force of the bolts combined. [6]

From there, **Equation 2:** $Force\ per\ Bolt = Blank\ Holder\ Force/N(\#\ of\ bolts)$ computes the values we need to find to determine the necessary torque to be applied to the bolts clamping our material.

To acquire this value, we can compute from our values we have currently in **Equation 3:** $Torque\ Spec. = Force\ per\ Bolt\ x\ Major\ Diameter\ of\ Bolt\ x\ K$, where K is a constant 0.2 for steel and we are ignoring the affects of lubrication in *Equation 3* since we are using dry bolts and threads. [3]

Material	Pressure	
	lb/in^2	MPa
Deep-drawing steel	300–450	1-3
Low-carbon steel	500	3-5
Aluminum and aluminum alloys	120-200	0.85-1.4
Aluminum alloys, special	500	3.5
Stainless steel, general	300-750	2-5
Stainless steel, austenitic	1000	7
Copper	175-250	1.25-1.75
Brass	200-300	1.40-2.0

Table 1: Hold Down Pressure Material Properties [6]

Min. and Max. Torque of Deep Drawing Steel				
Min. Blank Holding Pressure Required for Deep Drawing Steel	1	MPa	4	= length (in)
Max. Blank Holding Pressure Required for Deep Drawing Steel	3	MPa	4	= width (in)
Area of Sheet Metal Holding	9815.85252	mm^2	1	=Punch Dia. (in)
Minimum Holding Force	9815.85252	N	0	=Punch Uncovered
Maximum Holding Force	29447.5576	N	0	= % Uncovered
Min. Force per Bolt	1226.98157	N	15.2	= Area of Holding (in)
Max. Force per Bolt	3680.9447	N		
Min. Torque per Bolt	3.11653318	Nm		
Max. Torque per Bolt	9.34959953	Nm		

Figure 2: Min. and Max. Bolt Torque Computation for Deep Drawing Steel

Calculate Holding Force From Blank Dimensions				
Punch Diameter	25.4	mm	1	in
Blank Width	101.6	mm	4	in
Blank Length	101.6	mm	4	in
Punch Diameter Uncovered	0	mm	0	in.
% Ring Uncovered	0.00%			
Area of Sheet Metal Holding	9815.85252	mm^2		
Holding Pressure	2	MPa		
Holding Force	19631.705	N		
Force per Bolt	2453.96313	N		
Torque Specification	6.23306635	Nm		

Figure 3: Sample Bolt Torque Computation with Nominal Holding Pressure for Deep Drawing Steel

In *Figure* 2 and *Figure 3*, values highlighted gray must be inputted for each sample being tested to obtain the specified torque necessary for differing sample sizes and material which need to be recalculated with every sample size during our testing, since the altering holding area is a factor on the torque necessary as well as the holding pressure that is necessary to have proper clamping criteria. We can provide a safe range of torque for all deep drawing steel material properties as some may differ in the exact material. Noting that the bolts selected for clamping were ½-13 Grade 8 bolts, the maximum torque that may be applied to each bolt is 106 ft. lbs., and given the calculated torque required for each in *Figure 1* and *Figure 2*, we can safely use the hardware in our application. [9] Depending on material in use and dimensions being tested, using *Figure 2* starting at the nominal torque specification would be ideal if you do not have the capabilities to calculate the specific Holding Pressure using FEAs and adjusting the pressure between the values of torque depending on how the materials reacts. If the material shows signs of drawing in on the clamping ring, more torque needs applied to each bolt evenly. If the material shows signs of fracture close to or at the clamping area, the torque then needs to be reevaluated and reduced at each bolt evenly. Using a torque wrench, set the desired torque that is calculated to the maximum value of the range, which for our test setup is specified in *Figure 2* and if exhibiting signs of fracture near the clamping ring, torque may be decreased down to the minimum torque that can be applied to our material shown in *Figure 2* which will not allow material from the flange to draw inward, as we need to avoid this.

Lubrication

For testing, we required the use of a lubrication that has a high level of pressure resistance with the forces present, so Lucas Oil X-Tra Heavy Duty Grease was provided and used for the testing which worked properly but, because of the force exerted by the punch near the tip was so high it wanted to travel outwards. This caused us to have friction still very apparent at the tip, not allowing the material to stretch as wanted in that location. Danny Schaeffler, suggested to us to use hefty trash bags as a surface between the two metals that was able to stretch and would not be moved away from the tip of the punch, reducing the friction between the surfaces, and moving our fracture points from the lower sides of the dome to the top more. When collecting data results from circle grid testing this location of necking provides us with more accurate strain data for the Forming Limit Diagram the closer we can get it to the tip of the punch. Even with Mr. Schaeffler's suggestion though the necking was not being found in the ideal location.

Alignment of Dies and Punch

To ensure the proper drawing of the dies, there had to be multiple changes made to the press and other additions added to center and align the dies and punch as well as ensuring no movement during the process of testing. Starting with the apron of the press there was a substantial amount of play to be had from left to right that needed to be resolved and a slight amount in the other axis. To resolve the left to right movement that existed. Sketches were made on the apron to center the die between the posts on the press and marked for drilling on the apron to then allow for metal dowels to be inserted through the apron closing the gap between contact points on the apron and the posts to minimize the space allowed between the two surfaces causing the unwanted movement to almost nothing. Was the simplest and most cost-effective route to secure the apron. Front to back, the dimensions of the posts and apron also had a small gap that allowed for some play in the alignment of the punch over the die, which to solve the problem on this axis I worked with Mr. Aaron Trexler to print out two thinly designed shims out of ABS material *(Appendix F8)* to use to hold the apron steady during testing since there was a very marginal amount of error that existed in this axis but still needed a solution and with the density of the ABS and the ease of 3D printing, this was the best option to pursue to obtain a simple means to the problem existing. Now that the apron had been set to center the die, there still existed problems in the centering and alignment of the cylinder above as the assembly allowed for much movement in all directions without the cylinder being fastened by anything solid as it is held up by two spring and the upper portion sat inside a cupped area to help keep it from moving too far.

Figure 4: Cylinder misalignment for centering on upper assembly

Again, working with Mr. Trexler we decided to go forth with another 3D printed piece of ABS, a centering puck *(Appendix F7)* that protected the upper surface of the die as well as the punch when inserting into the dies for testing, but also aligned the punch outer diameter in center with the die inner diameters. Being able to create our own specified piece for this application and the price to 3D print versus manufacturing was much more suitable towards our budget. The outer diameter was set to match the inner diameter of the upper die to a depth that cannot cause interference with the test sample below. The inner diameter was then set to taper down to the dimension of the punch as to make insertion into the puck simplistic while still self-aligning the punch with the die as it approached the test sample through its range of movement.

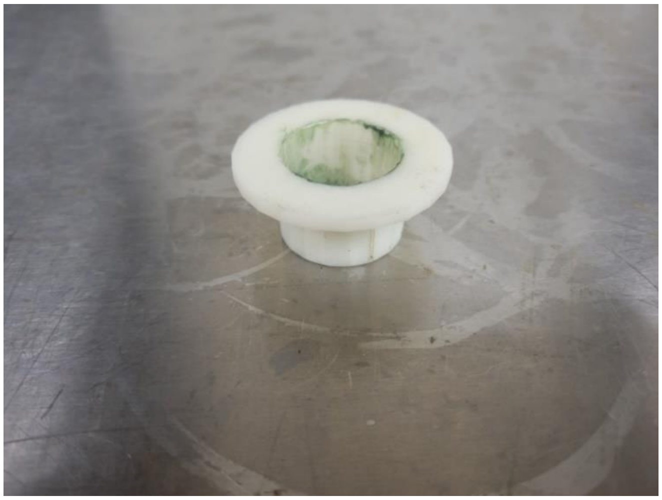


Figure 5: 3D Printed ABS Centering Puck

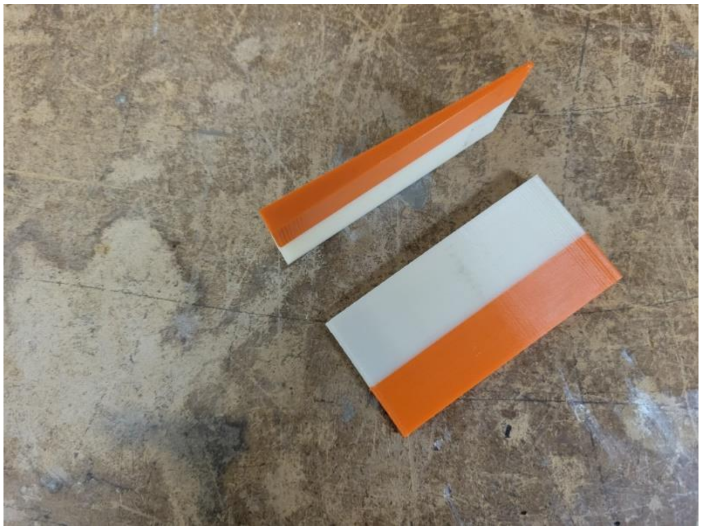


Figure 6: 3D Printed ABS Shims

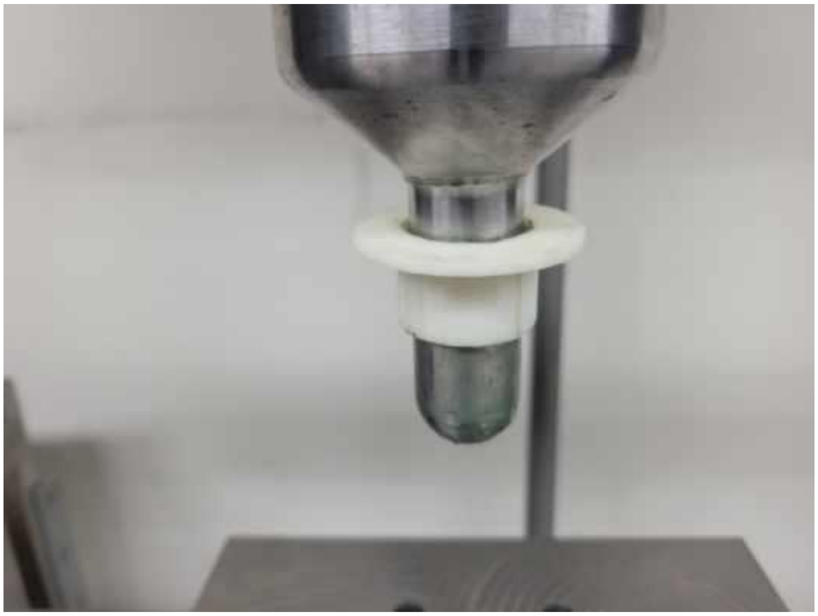


Figure 7: 3D Printed ABS shim shown with tight tolerancing to the punch

Future Track

Following the performing of initial testing there were many points of the design of the stand that came across to be fixed as working with just one person on the stand presented its own issues as well as issues with the initial design for safety and accuracy. Firstly, drawings of the dies should be updated to allow for machining of slotted handles, as both pieces are made of D2 steel and serve to have a large amount of weight to them without having any way to properly hold them and assemble and remove them from the press easily and quickly without any danger of pinching fingers or dropping the dies, in turn, damaging the precisely machined materials and creating the potential to have to machine again from scratch. Machining out slots on the sides of each of these pieces would allow for operators to have a safe area to hold onto giving them much better control and grip of the dies without compromising any of the design necessary for the test such as the bolt holes, holding ring, forming edge, and inner diameters of the dies. With a slot roughly 6 inches in length, ½ inches in height, and 1 inch in depth on the left and right sides of each die, with every hard corner machined to be filets, would greatly increase setup speed and safety as much of time was consumed in attempting to run tests as a single group member.

In discussion with safety being problematic, working in a team of one, it was possible to move the apron and die assembly up and down the press for setup. For a person not in proper physical shape though, problems could arise in either hurting their backs and/or causing damage to the setup of the stand. With the tight tolerances between the newly inserted metal dowels and the stand posts to reduce the side-to-side movement of the apron there is more resistance to move the weight upwards to its desired height which causes problems for the operator lifting the setup into the punch position and initially a setup of a jack underneath was looked into, but with the budget in mind and the fabricating needed to mount a steady jack setup underneath the apron was not plausible when thinking about materials and labor time as well. Knowing that there is only a 6 mm (0.236”) distance from punch nominal position to the surface of a material that is at the lower surface of the top die, to move the dies from the upper position for the punch to clear the die setup would only take the remaining 0.764” of movement in that direction. To ensure there is plenty of clearance between the top die and punch for assembly purposes to avoid interferences the clearance could be changed by 1.5” by adjusting the height of the apron. Looking at the option to machine out dowel holes for the pins on the press side posts it would be an easier job to complete, but with how much force is applied to that split I-beam, the issue of stress concentrations comes into the picture when keeping the stand as safe as possible for students. Best possible route to adjust the height of the apron down 1.5” would be to mark up the side post holes for the top position to be moved downward 1.5” and machine the material to allow the apron position to be moved to that level.

Figure 8: The upper position pin holes exist behind the apron in this image, focusing on those move them downward 1.5 inches to support the new height to set the pins to allow testing and assembly at

Doing so would in turn completely negate the need to even lift the apron up and down from set up position, avoiding costs of a jack and fabrication or the injury of a student operator. This was originally thought to be improbable as the prior group stated the cylinder had a max travel of 2 inches when in fact that did not stand true in testing. This change would need to be taken into effect though when discussing punch depth of travel until necking since the punch would travel further until initial contact is made, with a 1.5-inch change in height, punch depth would need to be increased 3.81 mm or just around 4 mm.

One last issue that is a potential source of error in testing the stand is the stability of the posts from left to right. Although the apron is now secured there is minimal amount of cross bracing in the harbor freight allowing it to angle itself slightly. Designing cross braces off the post pin holes between the two would be an easy way to resolve such issue for the future. But another and more effective option is to reengineer the post bracing in the front and back directions that are bolted to the ground and design and manufacture legs in the same fashion to fully secure the movements of the press in both axis as bolting it to the floor creates a much better base.

To solve these problems and help viewing of the test sample the setup can also be inverted such as in the drawing in *Appendix F12* with four guide posts to help align the dies and punch even more.

Manufacturing

Finalization of Previous Design

What was provided from the previous group going into this project was a 20-ton hydraulic press stand, machined top and bottom dies, and bolts, washers, and nuts for securing the samples in the dies. Much work was left to be determined in finalizing the functionality of the Dome Testing Stand coming into this project. The punch had been left to be milled out to for a threaded through hole allowing the thread screw to be able to tighten the punch down on the hydraulic cylinder and hold it into place during the testing procedure. The design of the top and bottom dies and the process in which they are clamped on the material, required that the bolts are allowed to pass through the upper surface of the apron to keep the dies anchored and evenly distributing the clamping force as was designed. Utilizing resources in the ME Lab in ASEC, I was able sketch out on the apron the necessary points for bolt placement and to drill out the holes properly allowing the previous designed dies to be incorporated with the Harbor Freight Press that was supplied.

Alignment of Dies and Punch

Other complications came along with the Harbor Freight press with incorporation of the dies. When setting up for testing there had shown to be many issues with aligning the punch and dies properly how they were designed to function, the apron had a lot of play as it only sat on top of the pins and slid around, and the hydraulic cylinder was only held up by springs and centered in a very loose tolerance centering ring. Possibly using the 20-ton press manufactured by Westward instead would be a more viable option as the cylinder is better mounted to the frame although the cost is much more than the press obtained from Harbor Freight. [10] To combat the apron loose on the pins, the apron was machined to allow metal dowels to be slid through holes and secure the movement of the apron with the dies centered underneath the punch above after sketching on the apron the proper placement for ½ inch aluminum dowels to secure any unnecessary movement in the left and right direction. Fixing the apron from moving in the other axis, shims were produced from ABS with the help of Mr. Aaron Trexler with the 3D printers in the ASEC ME Lab to help finally secure the apron from all unnecessary movement causing centering issues of our punch in our dies and on our test samples. Lastly, the unwanted movement of the punch that could cause damage to the die and created much of a difference in centering on the test samples, which was resolved by the design and utilization of a soft plastic puck also 3D printed in the ASEC ME Lab to the dimensions of the punch outer diameter and top die inner diameter, with a tapered inner diameter on the puck to allow for easy insertion into the puck to keep the two components (punch and dies) centered properly with each other.

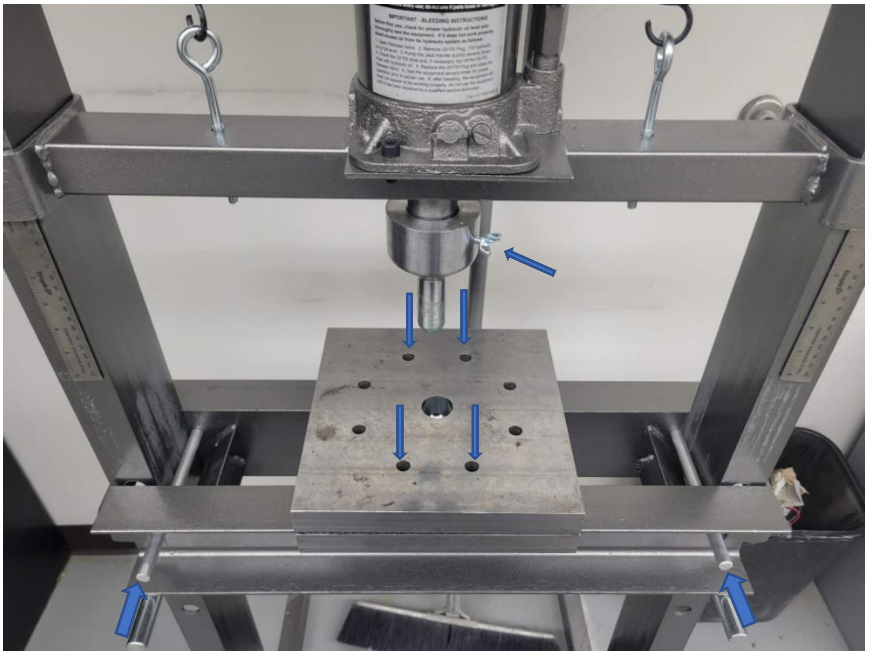


Figure 9: Holes machined through the apron to allow bolts to pass through dies, and new dowels inserted for alignment, as well as machining the punch for the thread screw to be used

Forming Limit Diagrams

4 inches											
4 inches (Δ 26-27 Mm)		3 inches (Δ 26 Mm)		2.5 inches (Δ 25 Mm)		2 inches (Δ 24 Mm)		1 inches (Δ ?? Mm)		0.5 inches (Δ ?? Mm)	
ε_1	ε_2	ε_1	ε_2	ε_1	ε_2	ε_1	ε_2	ε_1	ε_2	ε_1	ε_2
24%	54%	28%	56%	30%	57%	15%	55%				
26%	58%	29%	71%	25%	61%	20%	63%				
32%	58%	32%	65%	20%	53%	20%	63%				
						16%	53%				
						17%	67%				
						16%	64%				

Table 2: Excel Sheet to Input Data from Tests

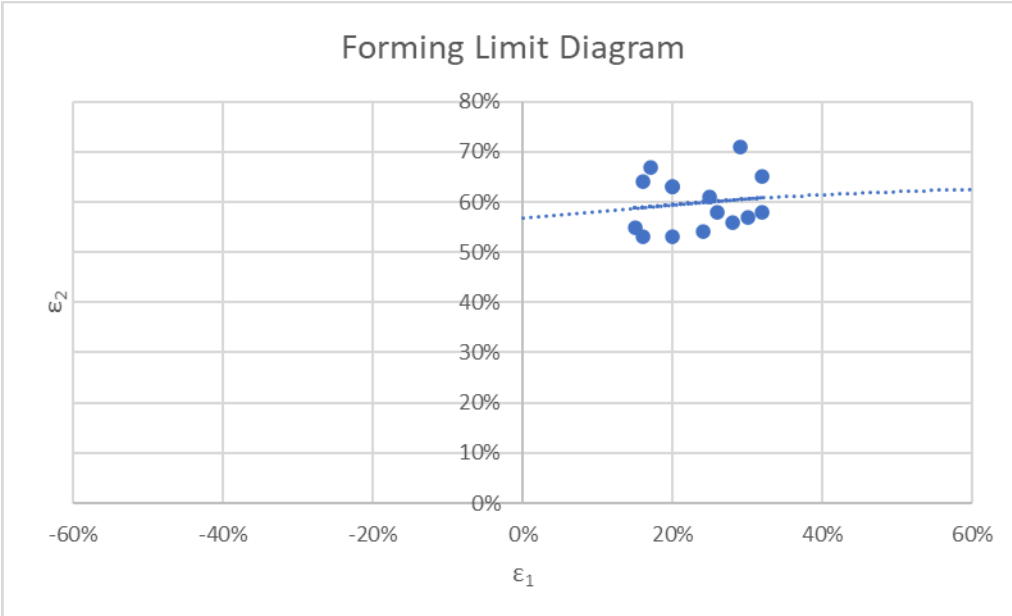


Figure 10: Plot will be Formed in Such Graph with the Excel Data Sheet

Using this chart for collection of data, you do not need to use every line necessary but instead any circles that cover the area of necking are all that are needed from each sample The excel sheet will take the data for strain 2 and strain 1 on the y and x axes accordingly. Using the data across all the sample sizes create for us the full spectrum of a predicted Forming Limit Diagram

Forming Limit Diagrams present a curve of the major and minor strains in comparison with each other to display the limits at which a material may be deep drawn. [7] *Figure 11* is a representation of the points that we may find at the necking point of our material during testing of the circle grid etched blanks. Any sort of strain that may occur that occurs above the limit curve proves to be a point of failure for said material during the deep drawing process.

From *Figure 10*, this shows the data collected for samples that are 4-inches, 3-inches, 2.5-inches, and 2 inches wide which only plots for us the right side of the curve where there is no compression existent in the material. The data began to present more differing values after the width was brough down to 2-inches and 2.5 inches as can be seen in *Figure 9*. This is an effect of the width being shrunk down to the diameter of the holding ring and also some inward, not stretching the material as much in one direction as is the 4-inch x 4-inch that feels the effects of the holding ring evenly in both axes. Each blank offers multiple points of data to be taken into account depending on the length of the necking area and for some materials, such as the 2-inch wide blank, there were two separate areas of necking on the sides of the dome to collect data from for the Forming Limit Curve of the material.

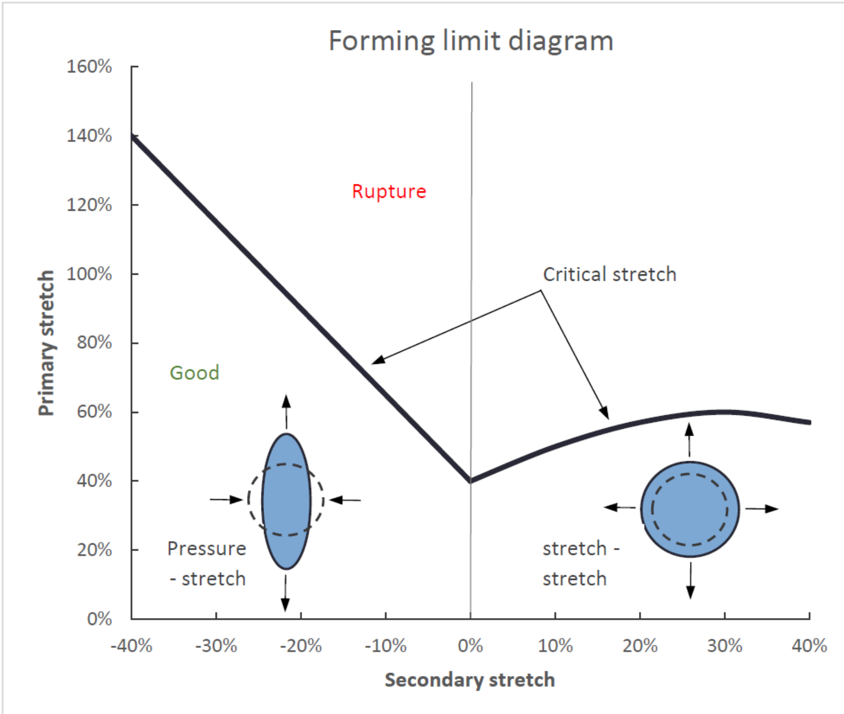


Figure 11

Dome Testing Stand

Purpose of Stand

The purpose of this such stand as a project is to offer a learning experience in determining a correct process in manufacturing, although on a much smaller scale than in the industry there is still experiences to be gained in ensuring proper forming of the material to produce accurate results. For a multitude of materials and material thicknesses there already exists many records of Forming Limit Diagrams to aid in the design of metal formed products. For Engineering students at The University of Akron, much of the practical learning comes from hands on experiences in labs, co-ops, and elective courses. One could review the many Forming Limit Diagrams available and understand what they are describing in theory but by giving students the opportunity to themselves drawing the material until its necking point and visually seeing and understanding the changes of the circle grid. By allowing these students to perform these tests and analyze the final data to formulate the Forming Limit Diagrams themselves, they have developed more skills that are useful in the job market. Forming limit curves change with material properties, material thicknesses, heat treating, etc. and with the use of this stand students will become capable in determining proper materials that may be used in forming products whether it be for student design groups, projects, or just for learning. By the completion of the test stand, it concludes a cost-effective method for providing Forming Limit Diagrams that can be easily calculated.

Initial Testing

Up to this point, half of the sample strip sizes have been able to be tested and have determined punch depth of the necking point of the material blank. The 4” x 4”, 4” x 3”, and 4” x 2.5” samples are the ones to be tested although there are some concerns in the testing for the 2.5” wide strips. From the tests there are issues with the holding force of the material the material because the width lies just outside of the diameter of the holding ring, and what can be seen is that the material wants to draw in based on the force of the bolts to hold the material in place that was calculated by the prior group which is why new bolt calculations were made and utilized afterwards. This issue presented itself even more so in testing the 4” x 0.5” strips under the same specifications. To attempt to punch the strips to a depth at which they reached their necking point the punch was pushed all the way until its limit and no observation could be made of the material necking or drawing in from viewing it through the bottom die. Though, once the test was disassembled it was very blatantly obvious that the strips had drawn in a substantial amount from their original dimensions. Previous calculations for necessary hold down force need to be recalculated with the fact the hold down area changes with each change of size sample being tested, the punch area never changes but the surface area of the blanks change each iteration altering the sufficient force needed to maintain lockdown because of the affects hold down area has on *Equation 1*. The found punch depths for the test samples are as follows for our setup of the linear scales, 25 mm for 4” x 4” sample, 26 mm for 4” x 3” sample, and 28.5 mm for 4” x 2.5” sample, at 6 mm is when the punch first contacts the surface of the material, and you begin to see any major deformation of the drawing at 8-10 mm. On the linear scales use the punch depths as references for materials with circle grids etched and observe closely for necking point as you approach that depth to avoid fracturing test pieces.

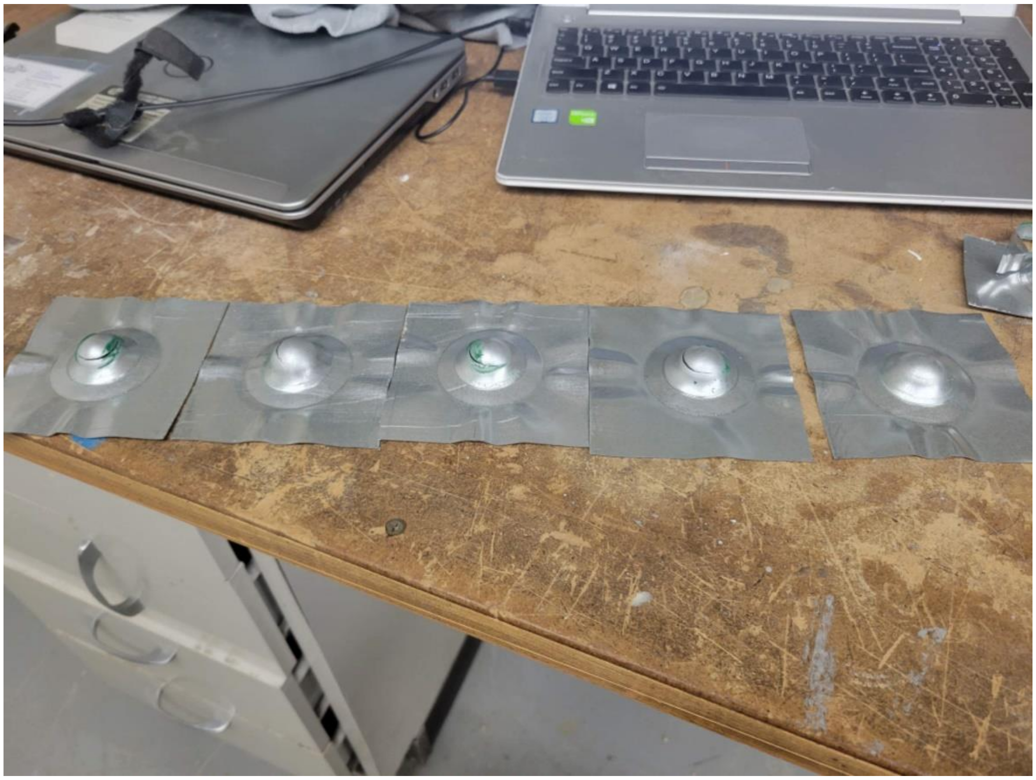


Figure 12: Initial Tests of 4-inch x 4-inch samples with varying wrinkling in each due to inconsistent tightening of bolts caused by incorrect and improper calculations

Figure 13: Initial Test of 4 inch x 0.5 inch with very noticeable problems with holding force acting on the blank

Figure 14: Initial Testing of 4-inch x 2.5-inch sample showing problems with wrinkling caused by incorrect holding force as well as interference on lower die chamfer which should be fileted instead to get rid of the sharp edges that the material catches itself on and improve metal flow [6]

Figure 15: Improvement of blank holding force in testing from the initial calculations provided on the right to the corrected torque on bolts on the left

Circle Grid Testing

Results

In *Figure 10* and *Table* 2 the data for the tests can be found. We were only able to find data for the right side of the graph without the slim strips able to be tested, but once the chamfered forming edge issue is resolved those will be able to find data for the left side of our plot. The collected data proves the bolt torque calculation corrections that were made proved sufficient in holding our blanks. The data of the curve varies a good amount as the length of the necking area itself covers multiple circles on the grid which vary in stretching covering different amounts of necking in the material, hence the varied data even in the multiple tests on the same blank. The procedure takes much time for one individual to complete in the current state, but it provides the results needed when testing our circle grids with the Mylar™ Strips on the right-hand side of the Forming Limit Diagram. Time must be taken to accurately read the strain strips in each direction of deformation to ensure the accuracy of the results, which comes down to those performing the procedure and their judgement. Final, punched blanks can be viewed in *Appendix F9*.

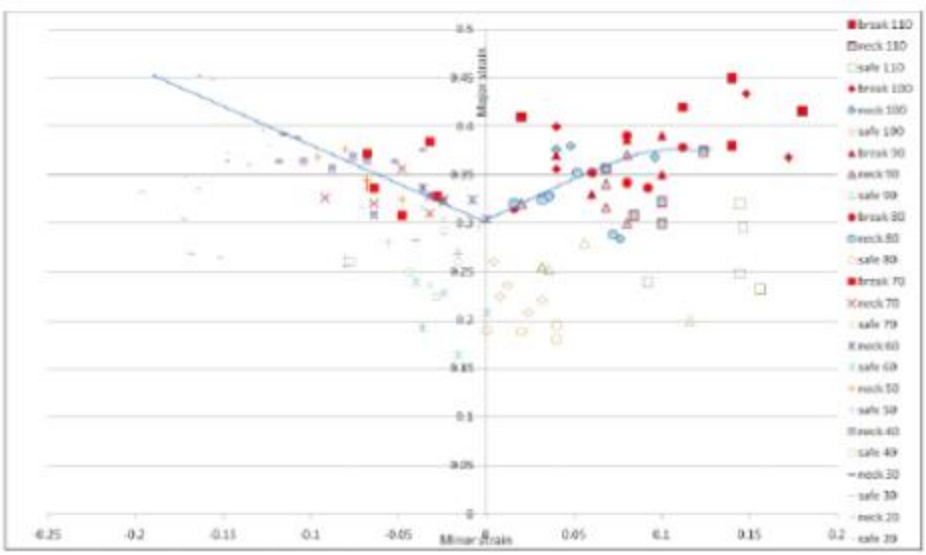


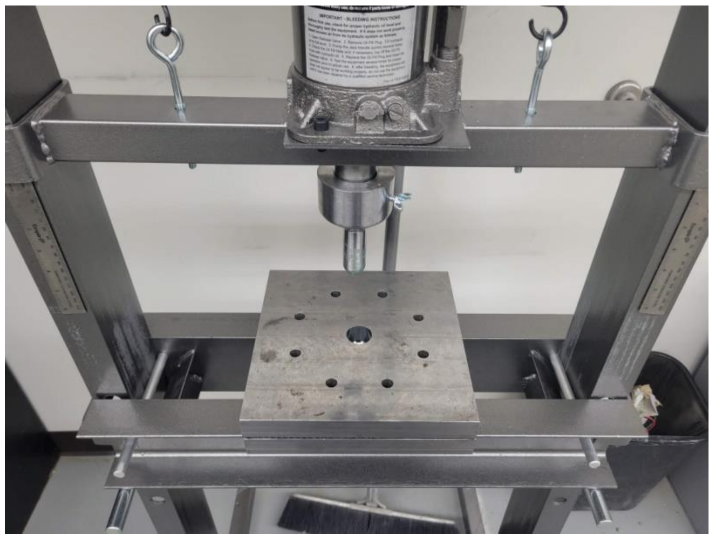
Figure 16: Data from EDD Steel at Room temperature

From data reviewed by measured Forming Limit Diagrams, it is hard to determine the accuracy of all tests results until many tests are performed as can be seen in *Figure 16*. The material tested was similar in shape but not thickness, as well as a punch double the size of that used in our testing, altering the data obtained but a similar plot of data can begin to be seen from the right side of data that was able to be obtained for *Figure 10*. [11] More than one size of each blank should be analyzed when attempting to formulate the full picture of the Forming Limit Curve.

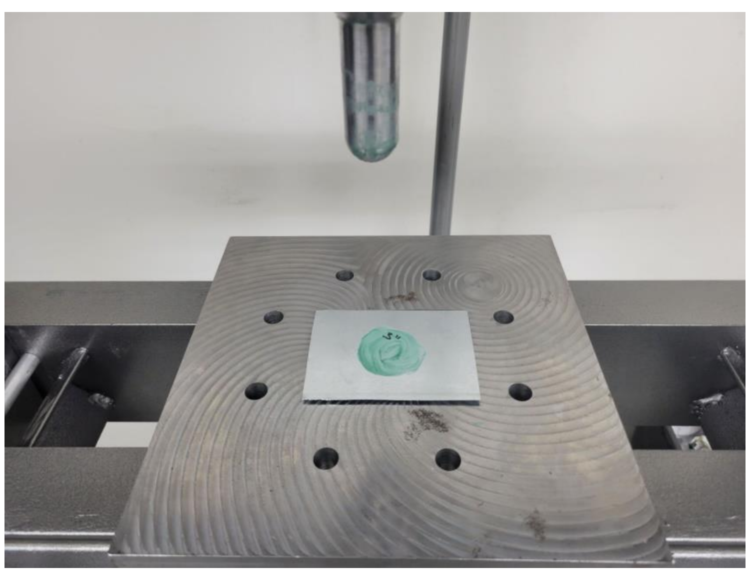
Procedure for Students

Gather together circle grid etched materials for testing that are all 4 inches and length ranging from widths of 4”, 3”, 2.5”, 2.5”, 2”, 1”, and 0.5” for the respected material.

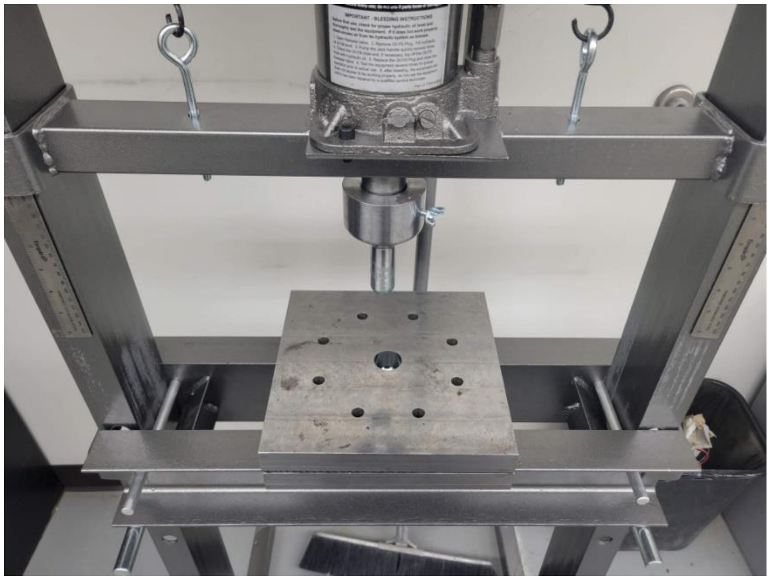
1. Set up bottom die to line up with bolt mounts on the press apron in the bottom position.



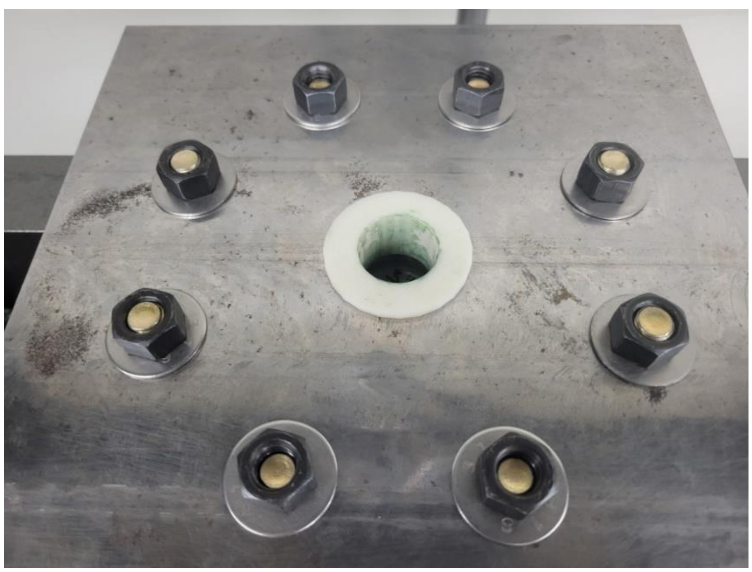
2. Set up test specimen on the hold down ring centered, length direction in left to right position and width in front to back positions.
3. Lubricate the surface of the test specimen contacting the punch with provided lubricants.



4. Ensure punch is tightened to the cylinder by the thread screw so that it is secure.
5. Lubricate the surface of the punch in contact with the test specimen during testing with provided lubricants.
6. Setup top die to be centered on the test specimen and bottom die.

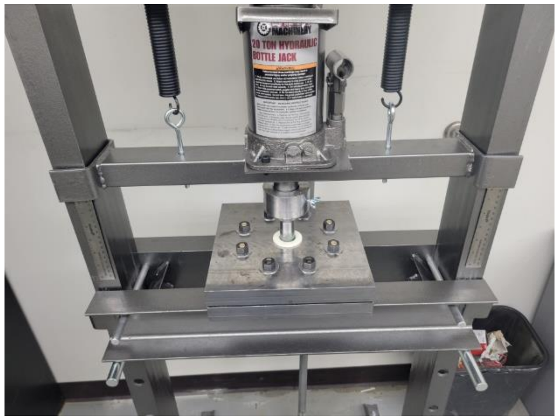


7. Align both dies with bolts through the designated place points.
    a. One washer on each side of the dies to evenly distribute forces.
    b. Tighten in star pattern to keep pressure even on the surface

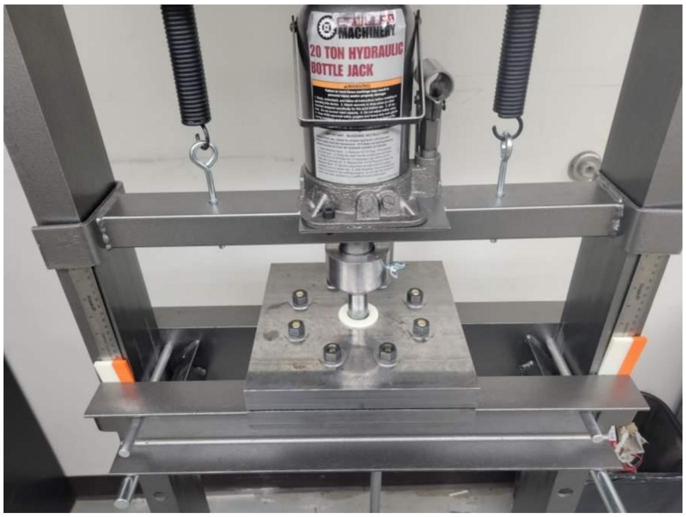


8. Hand tighten the bolts evenly across the dies.

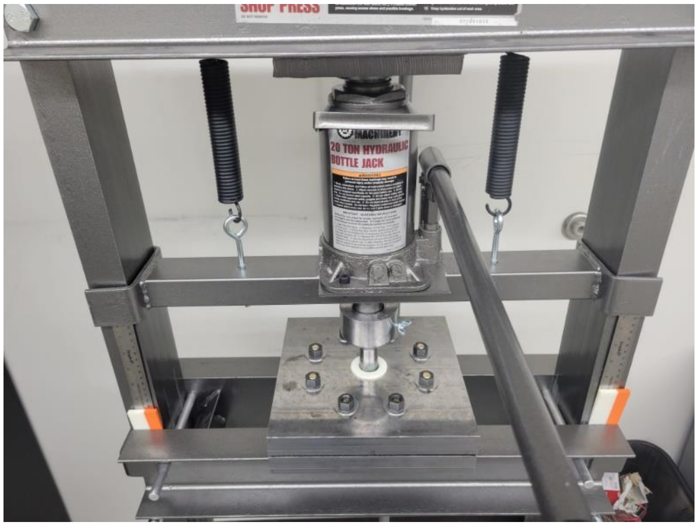
9. Tighten bolts to torque for the specified material being tested. (Calculate torque of bolts using Excel Spreadsheet for each size blank)
10. Place centering puck into the opening of the upper die before raising the apron to upper pin.
11. 1-2 group members lift the apron from the lower pins to designated height while the remaining member(s) move pins to new location to hold apron in place closer to the punch.



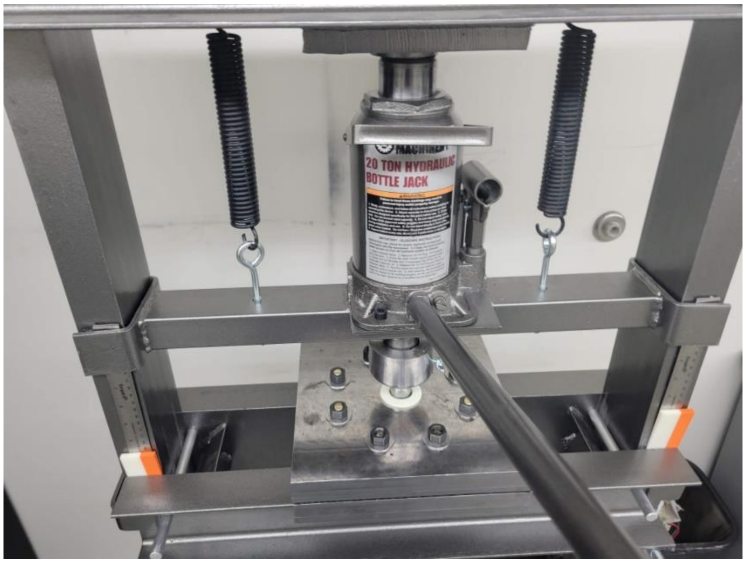
12. Once set, insert shims to tighten the apron to keep central alignment with the apron.



13. Look at the recommended punch depths for the specified material for the strip sizing.
14. Pump the handle to pressurize the hydraulic cylinder until it reaches close to the specified depth for the specimen close to necking.

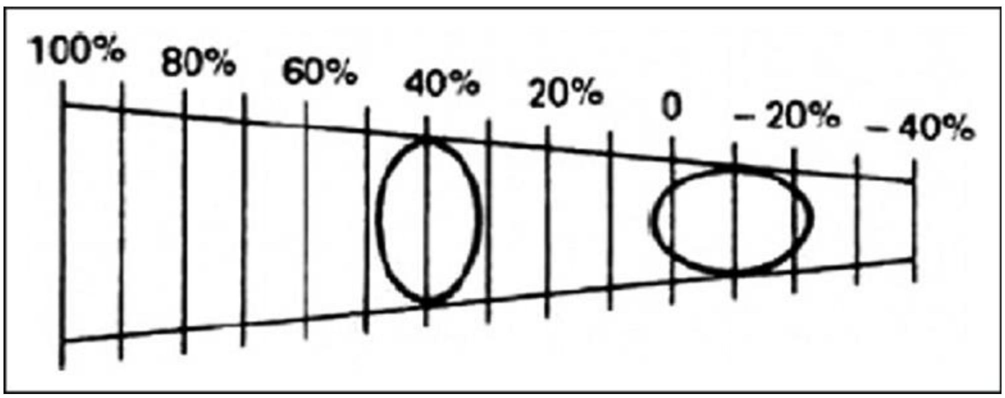


15. Another group member keeps an eye at the specimen from underneath until the material begins to display necking.
16. At the necking point, cease any movement and release the pressure in the cylinder by loosening the pressure valve with the pump handle end, to raise the punch back up out of the dies.



17. Lower the apron in the same procedure as step #11, proceed to loosen and remove all bolts on the die to remove the upper die and expose the test specimen.

18. Using the calibrated measurement tools (Mylar™ Strips), record the strain changes in the circle grid that surround the necking area of the specimen.
    a. Mylar™ Strips will show the percent change across the scale if used on the major and minor axis of the ellipses and circles in some cases.



19. Record values in the provided excel sheet to plot data points for each specimen, formulating the forming limit diagram for the test specimen and save as its own file named after the material.
20. Repeat the process for each size of the material to formulate the entire plot of limits.

DIC

Digital Image Correlation can be used after discussing with Dr. Kannan to help check the accuracy of the results gathered in circle grid analysis. After running multiple tests with the lower budget circle grid method, the opportunity to use this faculty members resource will help determine that the procedure and setup are adequate down the road when possible. DIC is similar to circle grids as either a grid of dots or rectangles are the initial imprint on the material, and cameras in conjunction with special software are utilized to determine the effective change of dimensions that are present looking pixel by pixel of the test subject giving a more accurate representation of the data being observed through the test.

Discussion

I entered the Dome Testing Stand project on my own with the help of Dr. Gopal Nadkarni as it was mainly to be focused on determining the testing and procedure needed for the formulation of the Forming Limit Diagrams. The project ended up being that and more which caused for delay in actual testing results for this semester. Much of the work done by the prior group on the project needed to be completed for assembly before even being able to test materials and the materials that were desired to be tested and already acquired were more than the stand could handle because of incorrect calculations of the Forming Force because of the thickness of these parts, which also would have caused interference between the clearance of the inner diameter of the top die and outer diameter of the punch during the drawing process. After a fair amount of work for my single member group to finish what the previous group still had to do, that was claimed to have been done and that it was ready to go for testing, and also fixing problems that existed in the setup not discussed previously, such as the alignment of the dies and punch, initial testing was finally able to be completed on materials following obtaining and etching obtaining a portion of such samples by the gracious help of Dr. Gopal Nadkarni and his contacts in the manufacturing industry, Danny Schaeffler and Patrick Dobrowolski. Testing itself presented many issues after diving further into the testing process at the beginning that have been resolved and just a small few left that have been identified and provided a direction on that will need to be resolved before final testing and data acquisition can be determined.

Conclusion

There is still some work left to complete for this project before anyone can gather proper data of the full spectrum of material blanks from the stand with our etched samples of the HDG Steel to provide the left and right sides of the Forming Limit Diagram but the stand has made a large step in the right direction proven with the data from the 4 samples collected. The goal was always to keep the budget as low as possible for this test stand and standing with such it, would be much easier to have obtained an Erichsen Cupping Test stand that already exists but where would the challenge and interest be in that for the students designing this stand and those that will use it in future classroom settings? Following the completion of the future track discussed, the stand will be suitable for all final testing of smaller strip. Much of these issues were not noticeable until testing was fully able to be completed and seeing our results, which took more time and analysis of the stand in front of us taking away from precious time to be had testing and ensuring the proper usage of the test stand that we desired but the improvements made and instruction of the few remaining leave us in an ideal place to begin to be able to determine results within a month. In the future it would be ideal for a team of at least three members to focus on different aspects of this project instead of one member attempting to juggle each of them between the understanding of the testing, design of the stand, and understanding of the materials in which they can then collaborate to finalize the testing procedure and analyzation of the results. Utilizing a team would have been much more beneficial to this term project and is necessary in going forth. From this project though I learned that communication is very vital between you and your group or department leader after I, myself had caused communication issues, and in doing so making it more difficult for myself and my advisor to progress this project, I learned how to correct the aspects of manufacturing that might go overlooked such as the alignment and correctness of the test even though it a smaller budget and scale stand it reflects on larger projects in large corporations, I have grown a vast understanding of Forming Limit Diagrams and their purpose in the Manufacturing Industry that I intend to use my knowledge in the industry in, and have learned how to improve working with my hands and machines to create a product that meets our needs, and most importantly learning how to juggle the many tasks that came along with this project on my own.

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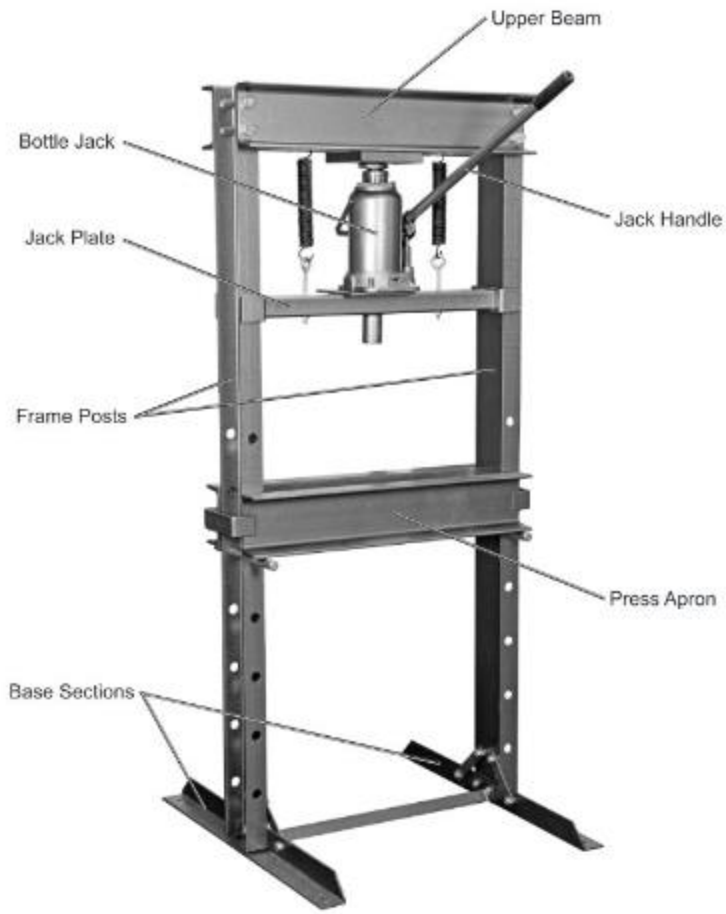
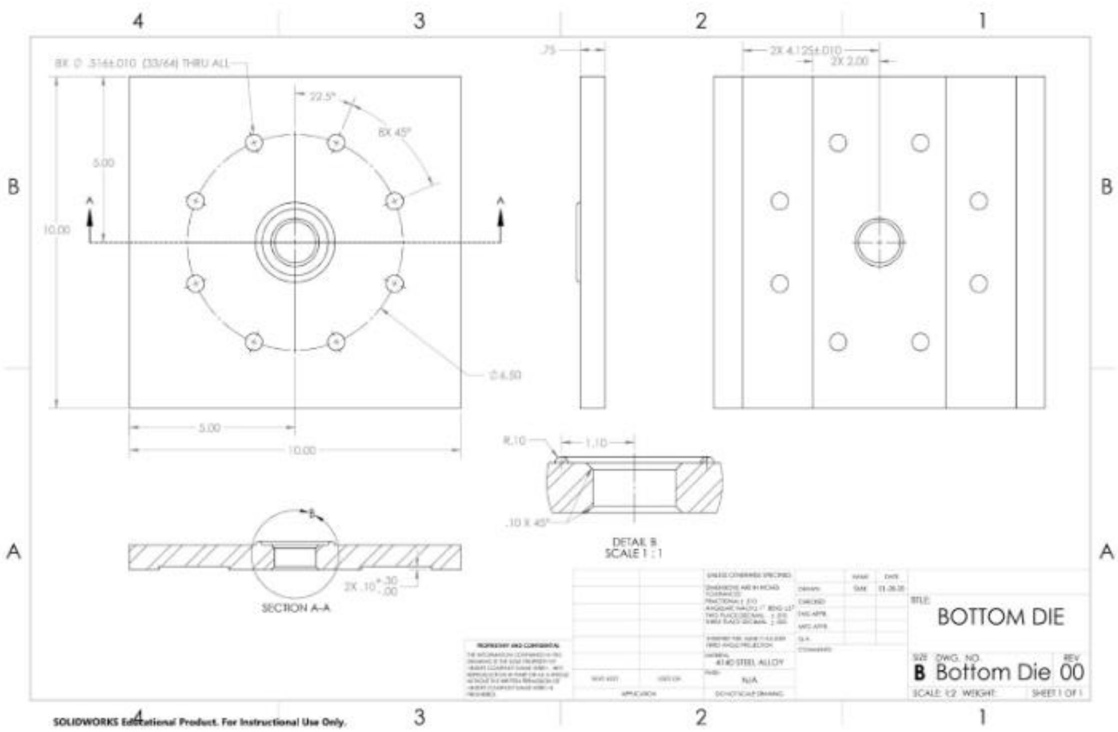
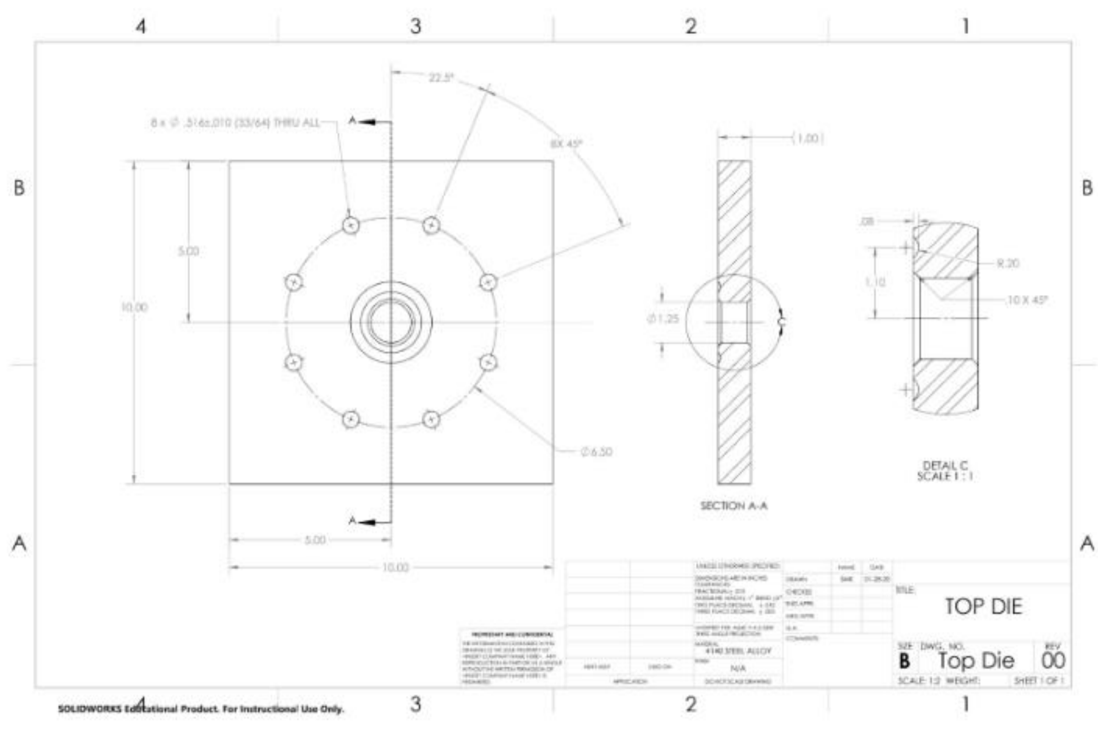
Appendix



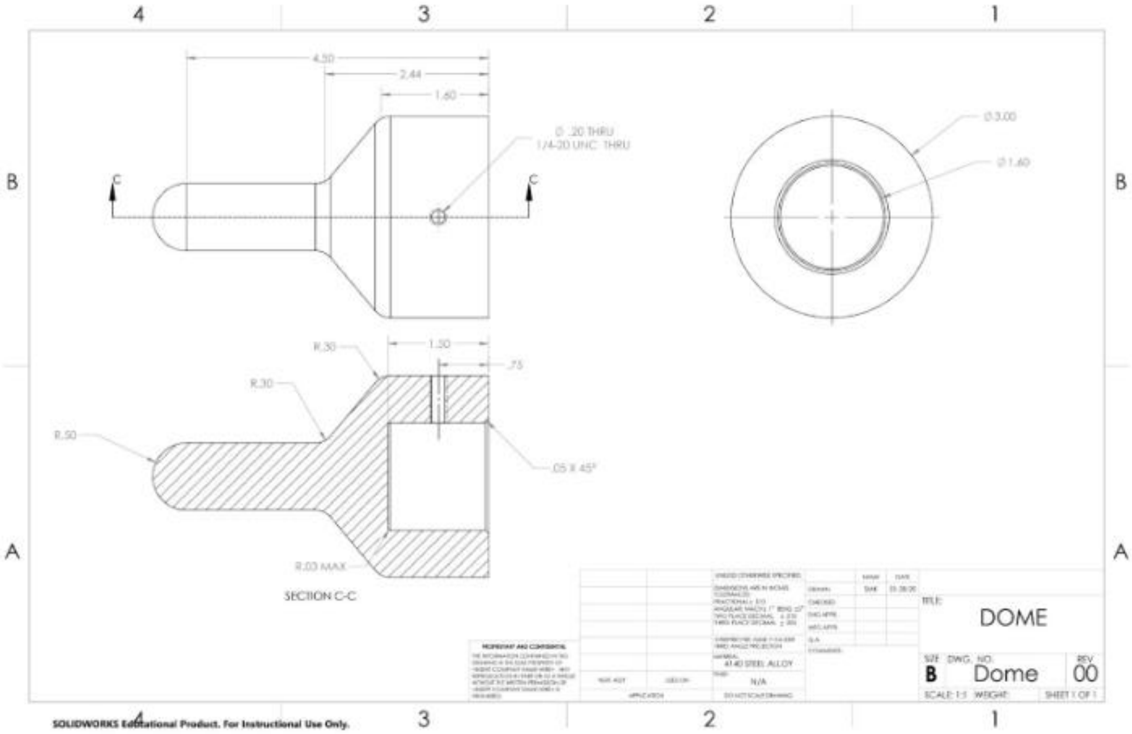
Appendix F1: Layout of Press in Use



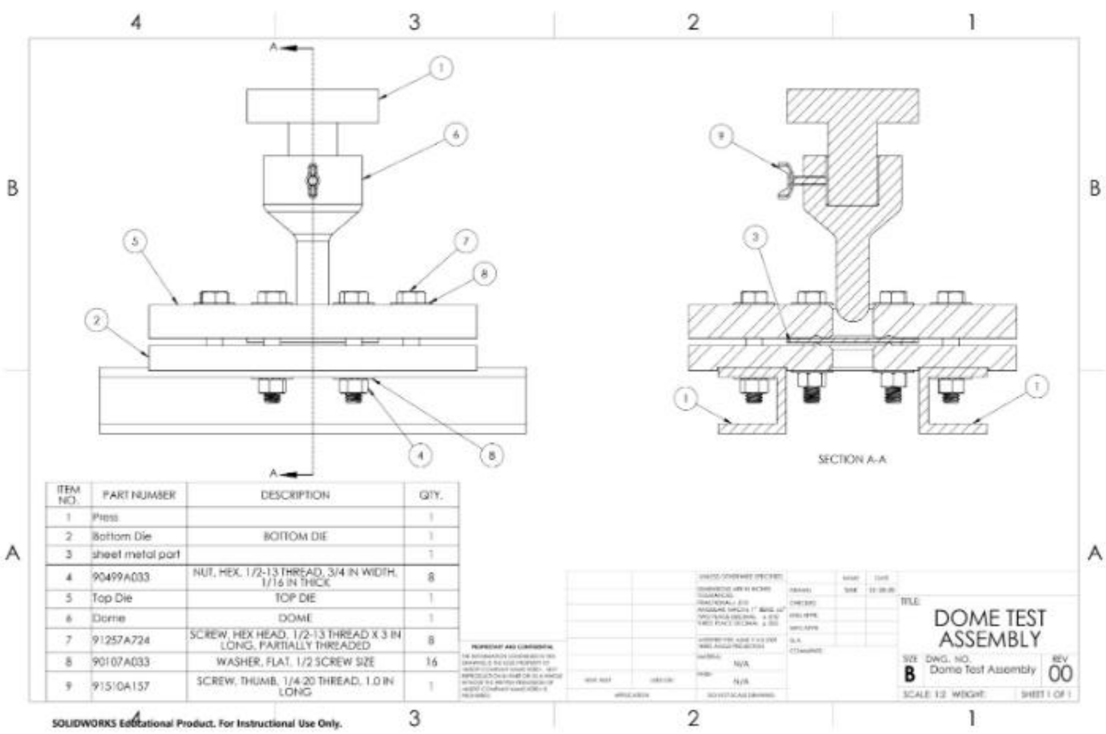
Appendix F2: Drawing of Bottom Die from Previous Team



Appendix F3: Drawing of Top Die from Previous Team

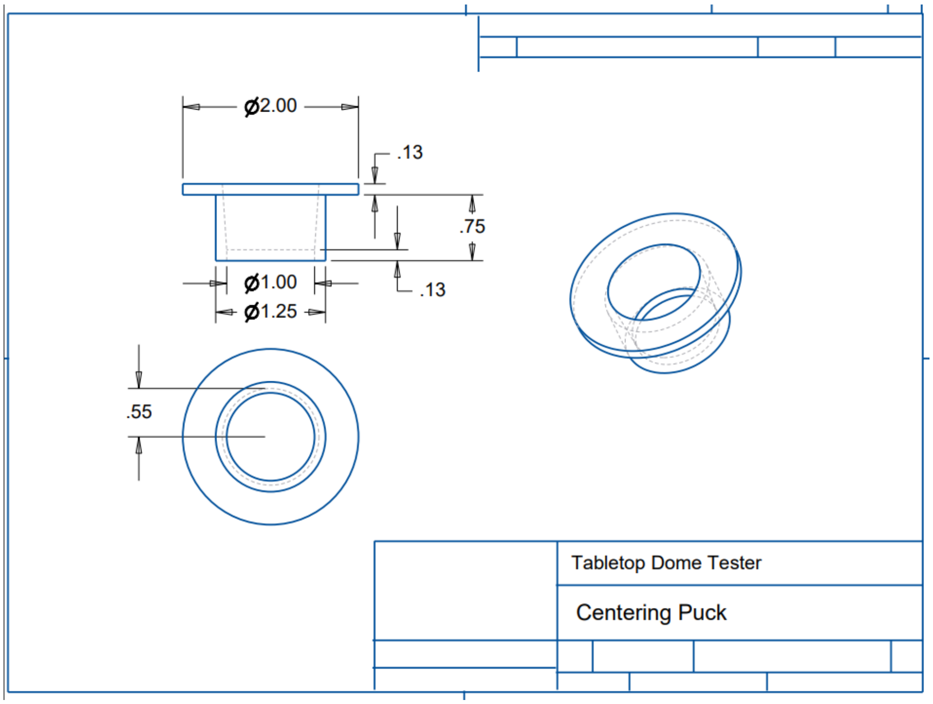


Appendix F4: Drawing of Punch from Previous Team

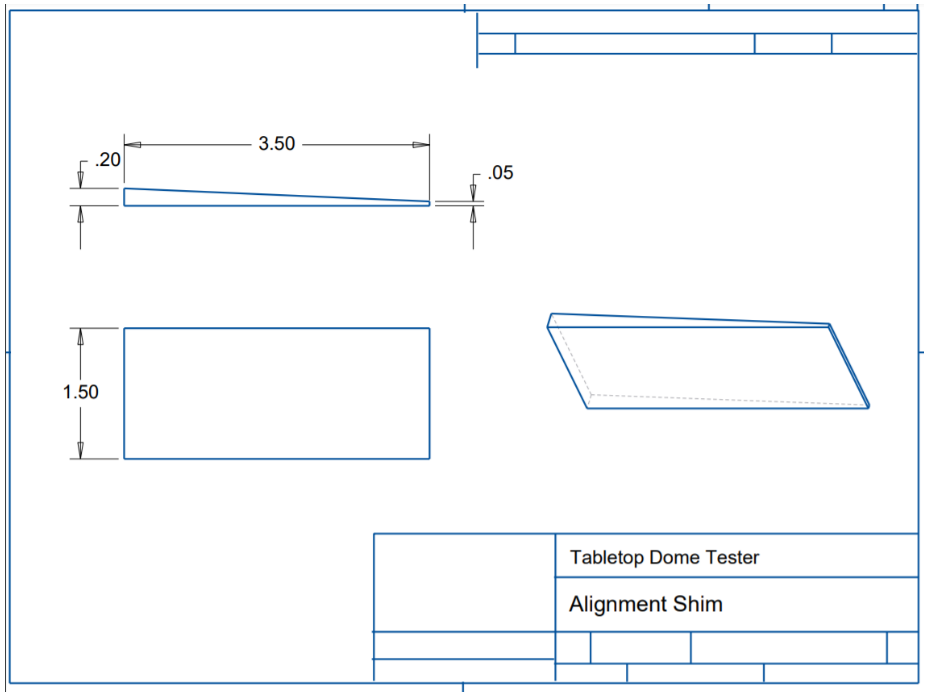


Appendix F5: Assembly Drawing from Previous Team

Appendix F6: Cabinet Located next to stand contains, dies, grease, wrenches, bolts, nuts, washers, 3D printed puck and shims, D2 Dies, and material for testing. Everything Necessary for the Dome Testing Stand.



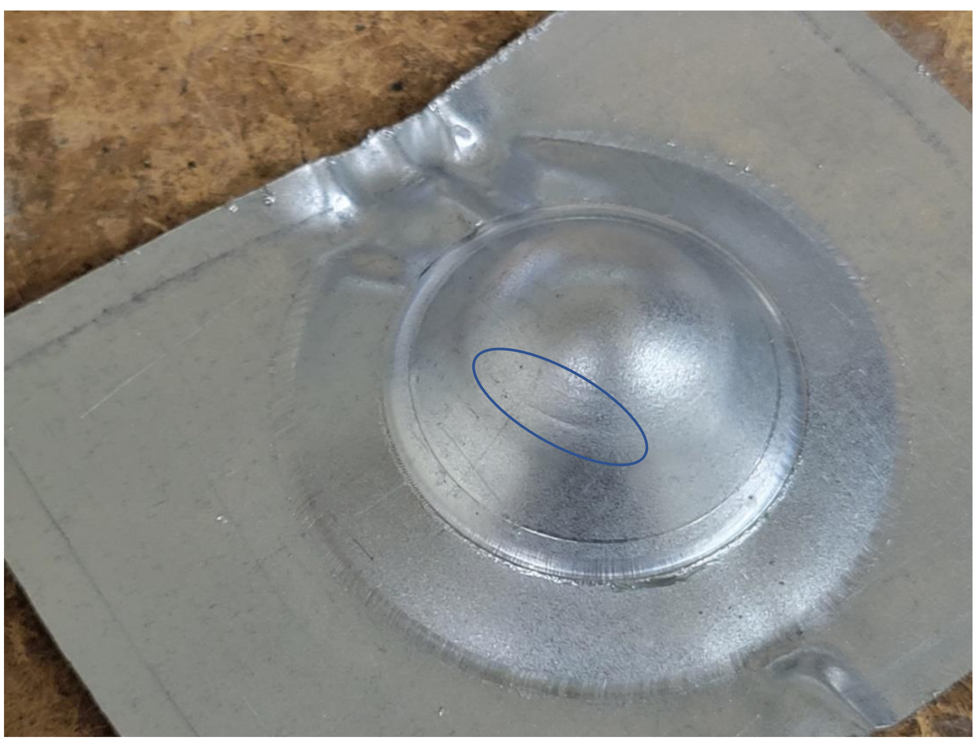
Appendix F7: Centering Puck Drawing



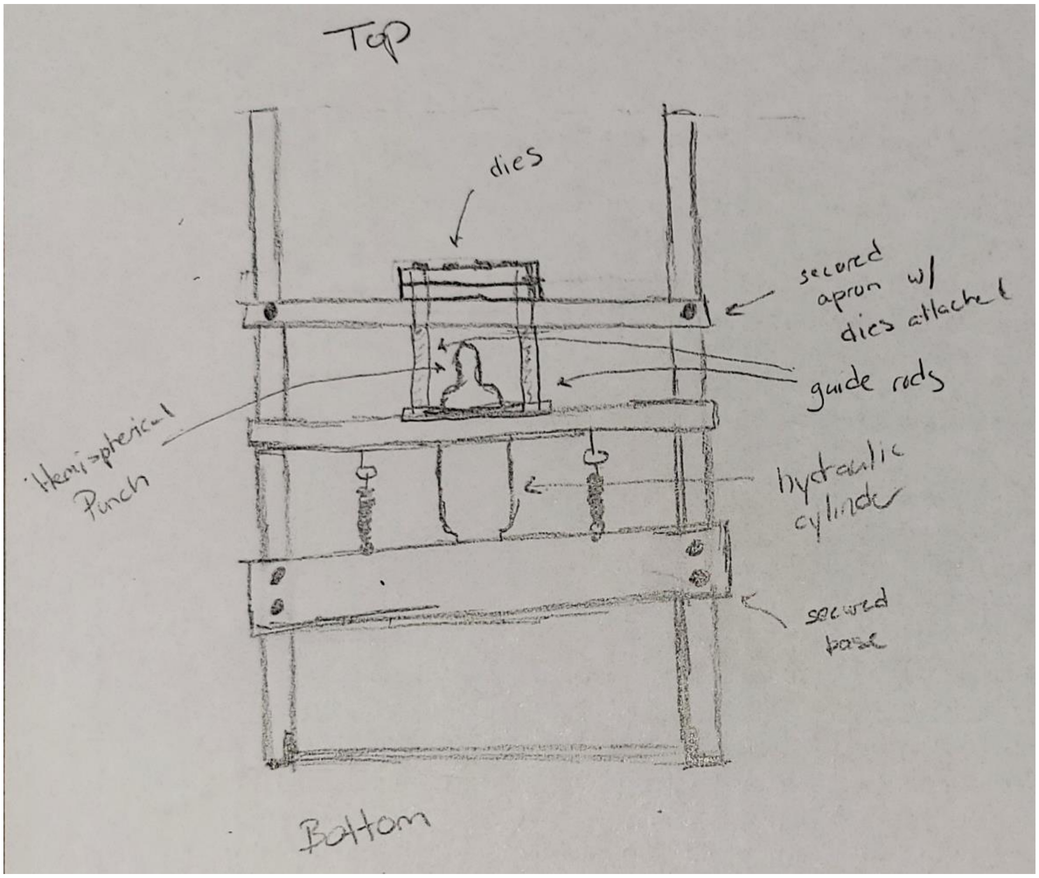
Appendix F8: Alignment Shim Drawing

Appendix F9: Circle Grid Tested Blanks

Appendix F10: All Samples that were tested and circle grid etched blanks in bottom row



Appendix F11: Example of necking point (Stretched strip of material circled)



Appendix F12: Inverting setup of dies