ME97 Design Packet

Tensile Test Device for Quality Control

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A) Executive Summary

Mechanical properties of materials are universally extracted from carefully designed experiments that examine the response of a specimen to an applied load or set of loads. Many of such tests are destructive in nature, causing the material to experience residual strain or fracture. Non-destructive testing is therefore of great interest for the obvious economical reason that the tested part can be used after the experiment. Non-destructive testing of materials is of particular interest in quality control since the specimen has already undergone a costly fabrication process.

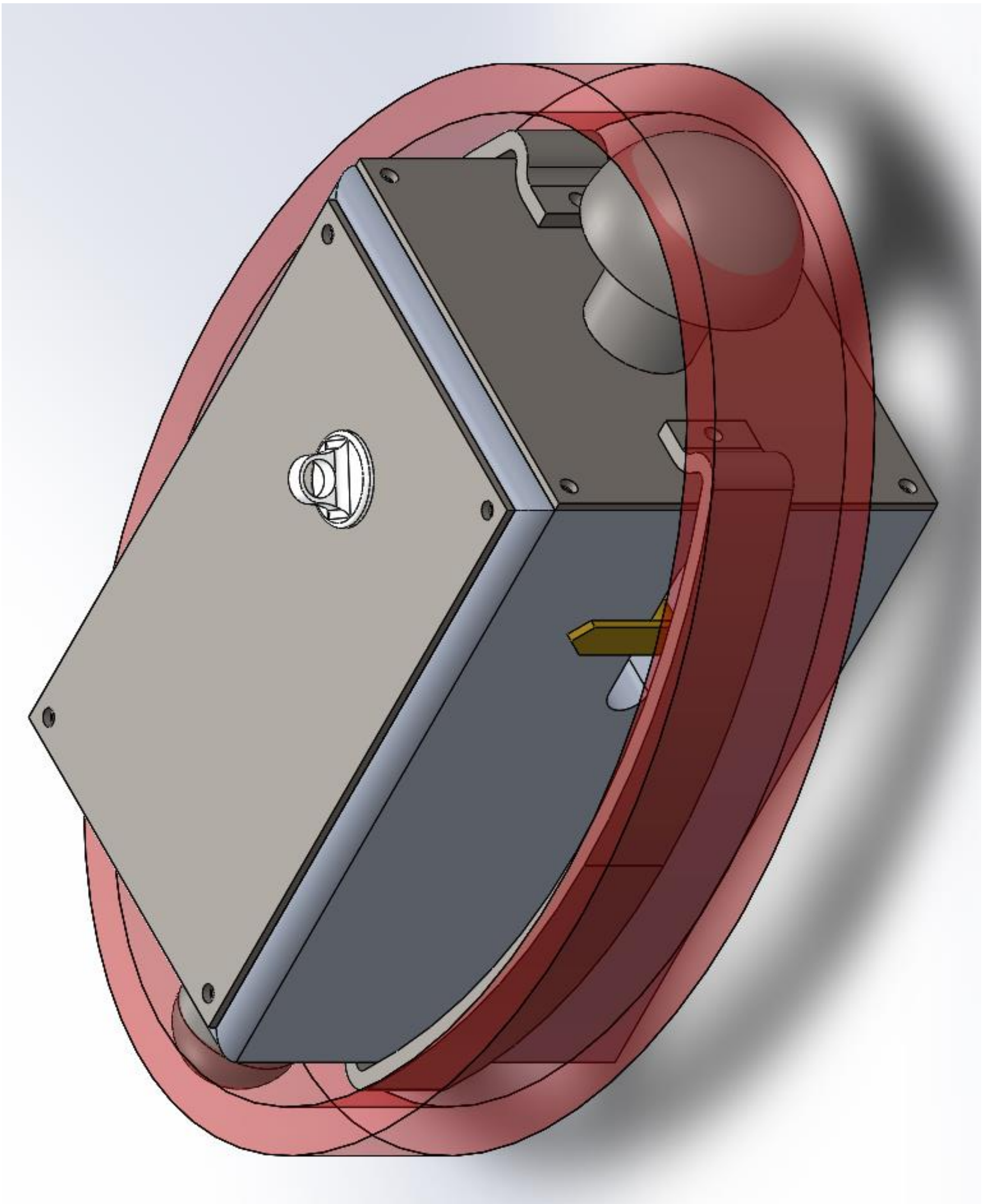
This report introduces a non-destructive method for identification of the onset of aging in polymers. Aging is a broad term that describes the chemical degradation of a polymer due to exposure to heat, UV radiation, and similar environmental factors. Aging has a significant effect on the mechanical properties of polymers (hardness, elastic modulus, density to name a few) and is therefore a key consideration in estimating the life cycle of a part.

Current methods of non-destructive testing for detection of aging include tracking of embrittlement through hardness, spectrometry, and instrumented indentation. Due to the cost and expertise needed for the latter methods, shore hardness is frequently examined as the figure of merit for the identification of aging. However, the shore hardness scale is very restrictive, and each durometer can only be used in conjunction with a narrow range of specimen. Moreover, embrittlement -caused by increased density of cross-linking- is often undone in longer periods of aging due to the unraveling of polymer chains. Finally, the material may undergo local fracture or pulverization, rendering the readings from the durometer unreliable.

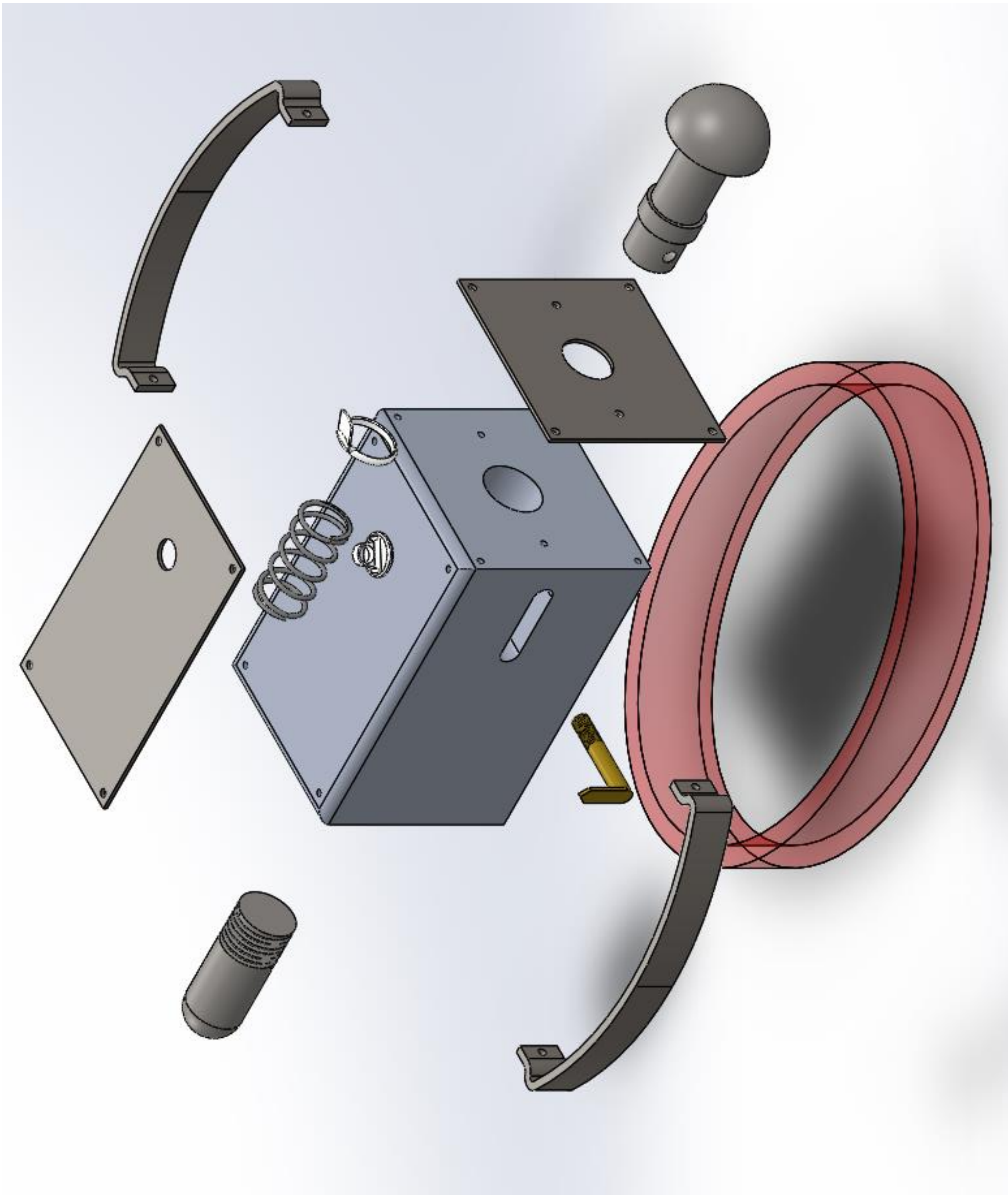
The proposed solution to this issue is a non-destructive tensile test device that applies a known force to the specimen through a spring-loaded plunger. By comparing the load and the resulting displacement, the device produces a qualitative estimate of the compliance of the specimen. Combined with a reference value, this reading provides a figure of merit that can be used in post-processing quality control. This device enables cheap, simple, and relatively robust testing that enables easy examination of polymer aging for finished products.

B) Renderings

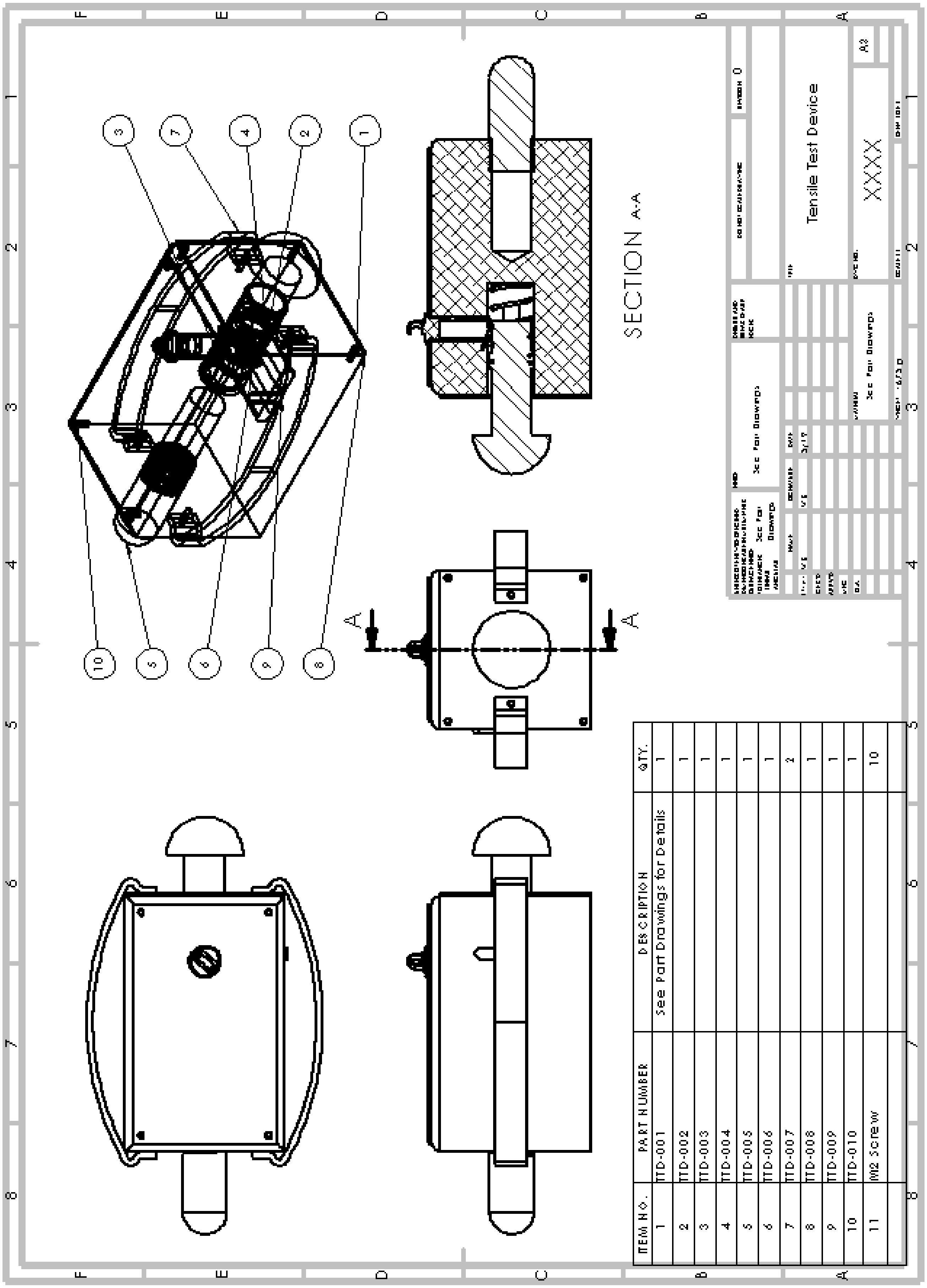
1) Device Rendering



Device Rendering – Exploded View



Overall Assembly



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	TTD-001	See Part Drawings for Details	1
2	TTD-002		1
3	TTD-003		1
4	TTD-004		1
5	TTD-005		1
6	TTD-006		1
7	TTD-007		2
8	TTD-008		1
9	TTD-009		1
10	TTD-010		1
11	M2 Screw		10

C) Capabilities and Specifications

Spring Number	Rate (N/mm)	Force Applied per Grading of Displacement (N)	Minimum Compression Length (mm)	Outer diameter (mm)	Length (mm)	Part Number (McMaster Carr)
#1	1.93	0.965	7.4	10.7	25.4	9657K307
#2	1.73	0.865	6.6	12.7	25.4	9657K312
#3	1.44	0.720	7.6	9.53	25.4	9657K306
#4	1.00	0.50	8.13	6.35	31.75	9657K328
#5	0.701	0.351	5.8	7.95	25.4	9657K303

Fixed End Number	Recommended Specimen Diameter (Pre-loaded) (mm)
#1	125
#2	130
#3	135
#4	140
#5	145

Number of Gradings: 16
Distance Between Gradings: 0.5mm (See table for applied force per grading)
Maximum Reset Force (N): 15.5 N (3.5 lbs.)
The device can be operated with any of the springs or fixed end combinations from the available options.

The device produces one output parameter that can be used to create a qualitative approximation of compliance – this is the grading that can be read from the side of the device and corresponds to a certain applied force by the plunger spring. Greater values of the compliance parameter correspond to reducing stiffness. This parameter is compared to the reference grading for the specimen. An acceptable tolerance is imposed by the inspector for the compliance parameter; deviation from this tolerance corresponds to a decrease in elastic modulus and is indicative of the onset of plastic aging in the test specimen.

The specimen must be circular or elliptic in geometry to be easily mounted on the device. Examples include round rubber bands, O-rings, circular rubber sealings, and thin-walled cylindrical plastic components.

To operate the device:

1) Push the plunger inwards to the locked position to apply spring pressure.
2) Position the specimen between the two prongs, ensuring that the test piece is pre-loaded. Use an appropriately sized fixed end if the gap between the ends is too small for the specimen.
3) Press the button to release the plunger.
4) Read the grading using the indicator on the side of the device.
5) Compare the compliance parameter to the acceptable tolerance.

To change fixed end:

1) Consult the relevant table to select an appropriately sized prong.
2) Unscrew the fixed end and screw in the substitute part.

To change the Spring:

1) Consult the relevant table to select an appropriately stiff spring.
2) Unscrew the indicator while holding on to the plunger.
3) Unscrew the front plate and carefully remove the plunger.
   Warning: Plunger will be under spring pressure. Remove with care.
4) Remove the spring and replace with the substitute part.

D) Discussion of Design Decisions and Principles

As briefly discussed in the executive summary, this device is designed with a very specific intent: to detect the onset of aging in finished polymeric components by tensioning a specimen. Due to the intended role of the device in quality controlled, it is designed to be simple, portable, flexible, and easy to operate while avoiding the technical limitations that similar methods have in detecting polymer degradation.

The most fundamental design decision behind the device is the mechanical property that is used to identify aging – stiffness, or, indirectly, elastic modulus. Hardness tests require an ideal test surface that does not pulverize or change local geometry to get reliable readings. Moreover, embrittlement is countered by some of the forces involved in degradation – namely the unraveling of polymer chains. This creates the need for instrumented indentation and tracking of the load-displacement curve for a large set of applied forces to observe and account for such artifacts. However, instrumented indentation is expensive, complicated, and often difficult to carry to the testing site. While stiffness depends on the same material properties that dictate hardness (polymer chain length and cross-linking), it depends on the entire geometry of the specimen and avoids much of the local variations that are inherent to indenters. This means that two points on the load-displacement curve are enough to provide a qualitative view of compliance and, inversely, stiffness. The cost of this decision is the natural limitation that is imposed on the geometry of the specimen – the test sample must be round, as discussed in the previous section.

Beyond its working principle, the device is designed for simplicity and ease of use. The use of a spring-loaded plunger and distance gradings eliminates the need for an electrical interface or power supply. This makes the tester very easy to transport, making it an excellent candidate for on-site testing. Moreover, the simplicity of the mechanism means that the device is relatively easy to use. This is highlighted in the instructions provided earlier. Finally, the device can be retrofitted with a range of springs and fixed prongs to eliminate the need for multiple testing apparatus – as with shore durometers. Lastly, the qualitative nature of the compliance parameter means that the specimen can be easily compared to a standard value to determine the onset of aging in the batch of parts it represents.

E) Risk Assessment

Risk	Hazard	Mitigation
Locking washer fails	Very High	Locking washer is designed to tolerate applied loads and fabricated from compliant material to deform as needed without yielding or fracture.
Plunger fails to travel in the cavity	High	Sliding fit introduced between the plunger and the cavity.
Applied fails to deform the specimen	Medium	A range of springs are available for different specimen.
Plunger leaving the frame	Medium	1mm Thick front plate acts as the dead stop for the plunger.
Plunger striking the user during operation	Low	Spring stiffnesses are selected to avoid potentially dangerous forces.
Indicator damaging the user during disassembly	Very Low	The brass plate is thickened, filleted, deburred.
Button Leaving the frame	Negligible	Button is captive and extremely light with little energy in case of ejection.
Device falling and damaging the user	Low	The device is designed to be relatively light but must be handled with care.

F) Cost

Item	Raw Materials	Fabrication Time (Hrs)	Total Part Cost	
Frame	50	4	450	
Plunger	25	4	425	
Fixed End	25	2	225	
Top Plate	20	2	220	
Front Plate	20	2	220	
Washer	10	1	110	
Button	10	1	110	
Indicator	20	3	320	
Side Guide	20	2	220	
Spring	10		10	Overall Cost
		Packaging and Misc.	50	2360

All figures are provided in dollars.
Labor price approximated at $100 per hour.

G) Schedule

Phase	Approximate Time (Weeks)
Background Research	2
Concept Generation	2
Concept Selection	1
Preliminary Design	1
Detailed Design	2
Design Revision	1
Finalized Design and Drawings	1
Fabrication	2
Testing	1
Total Development Time	13

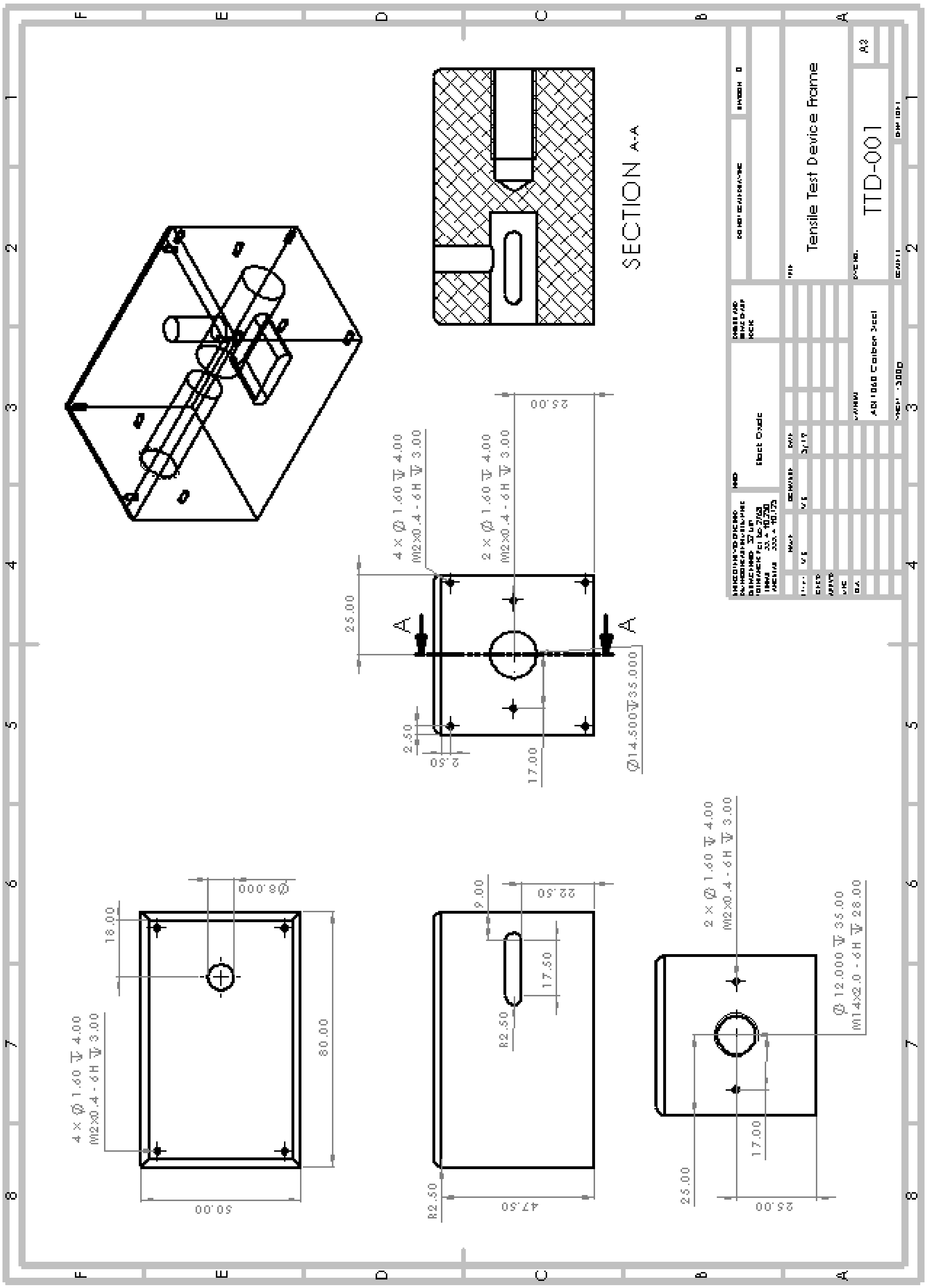
H) Future Capabilities

Capability	Difficulty of Implementation	Description
Expanded Range of Springs and fixed ends	Low	The selection of springs and fixed prongs can be expanded to facilitate testing of more specimen with a greater range of stiffnesses.
Digital Readout	Medium	The analog readout can be replaced with an electronic display to facilitate usage and provide more accurate results.
Digital User Interface	High	A more sophisticated interface can be implemented which will store a reference compliance and automatically identify faulty specimens.
Integrated Mounting Tool for Different Specimen Geometries	High	One or more dedicated mounting tools can be included to increase the range of specimen geometries (linear, rectangular, etc.) that are handled by the device.

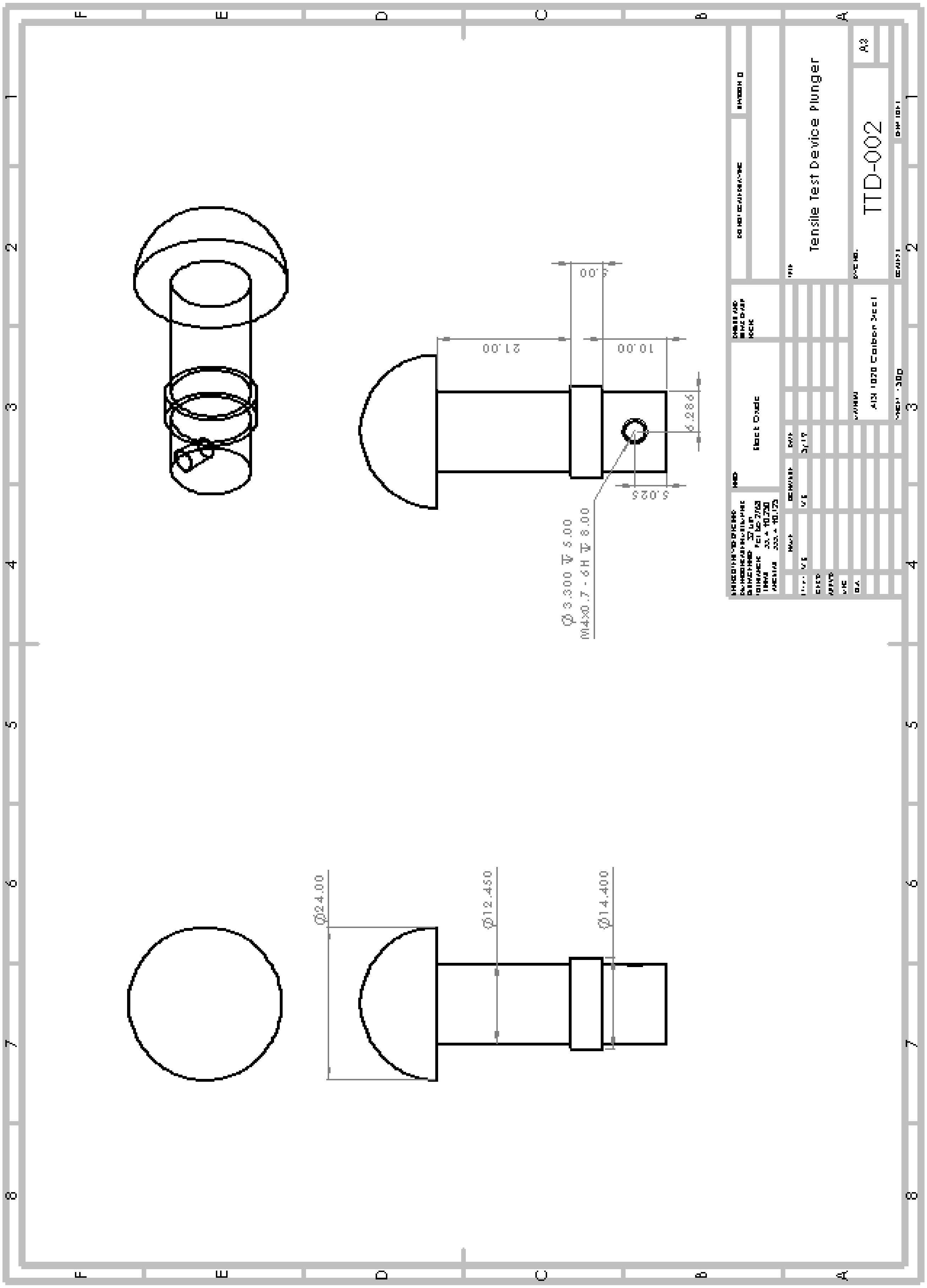
Appendix A

Engineering Drawings

A) Frame

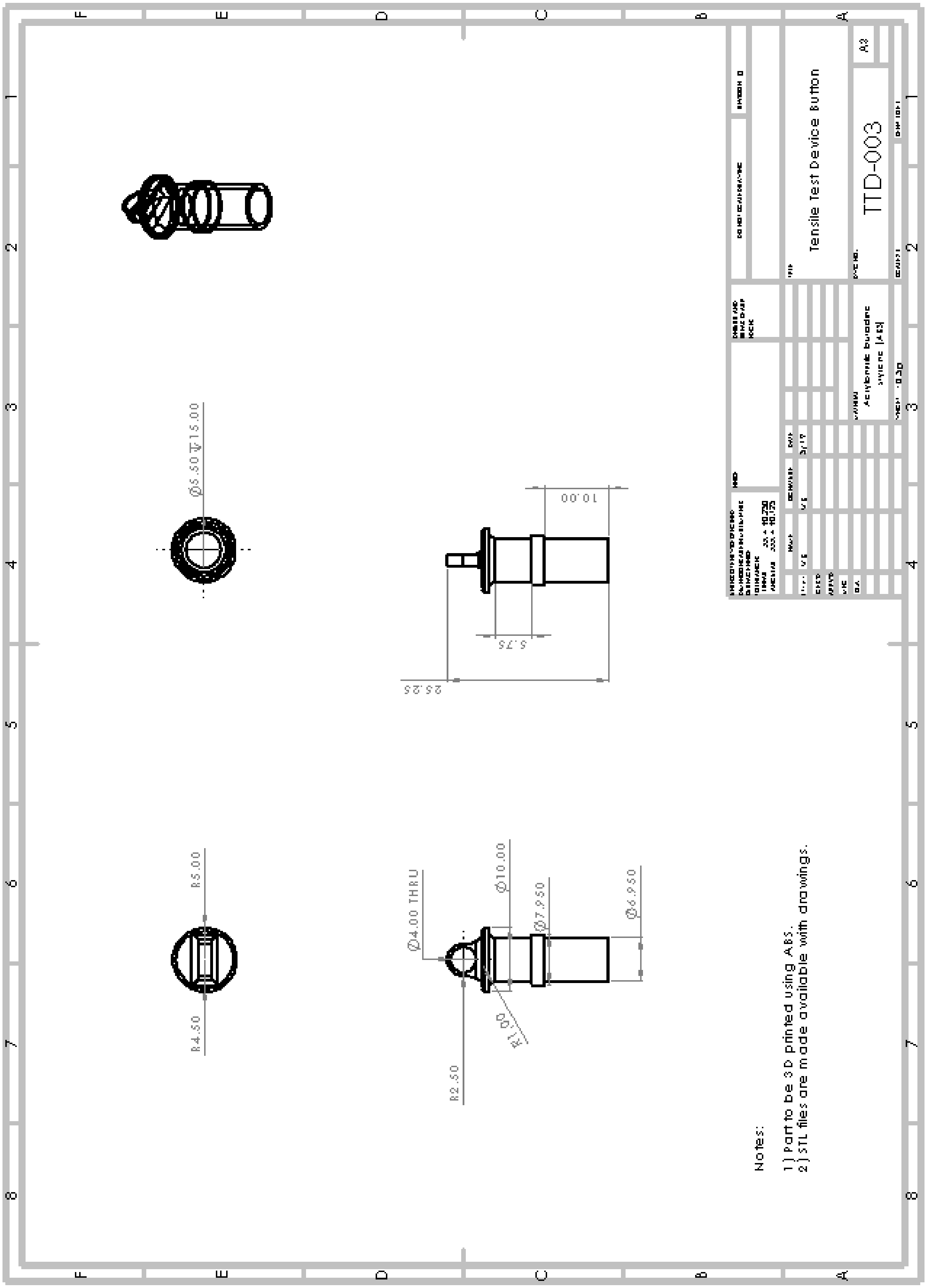


B) Plunger

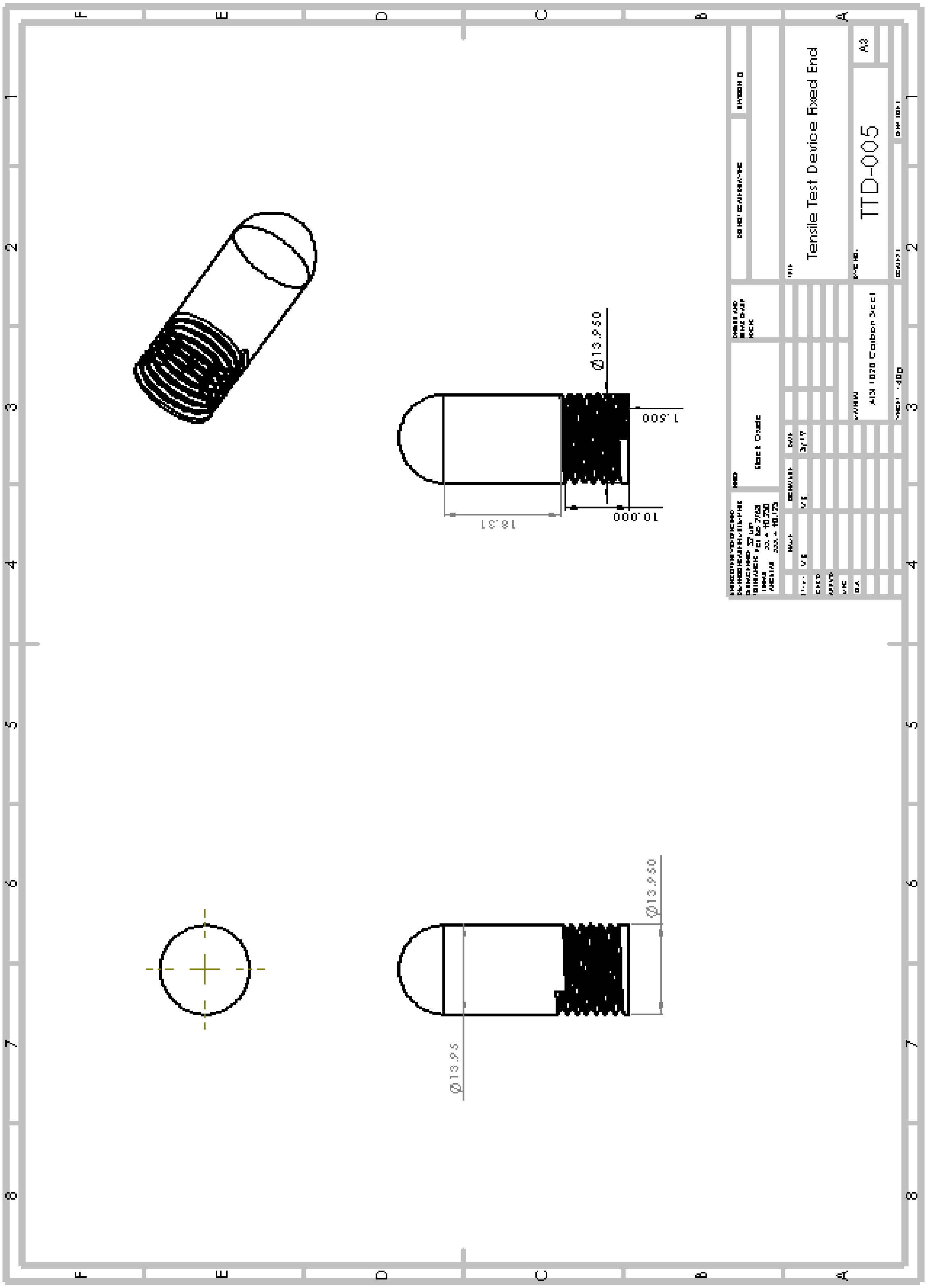


Tensile Test Device Plunger
TTD-002
A3
AISI 1020 Carbon Steel
21.00
10.00
5.00
5.025
6.286
Ø 3.300 ⊽ 5.00
M4x0.7 - 6H ⊽ 8.00
Ø24.00
Ø12.450
Ø14.400

C) Button

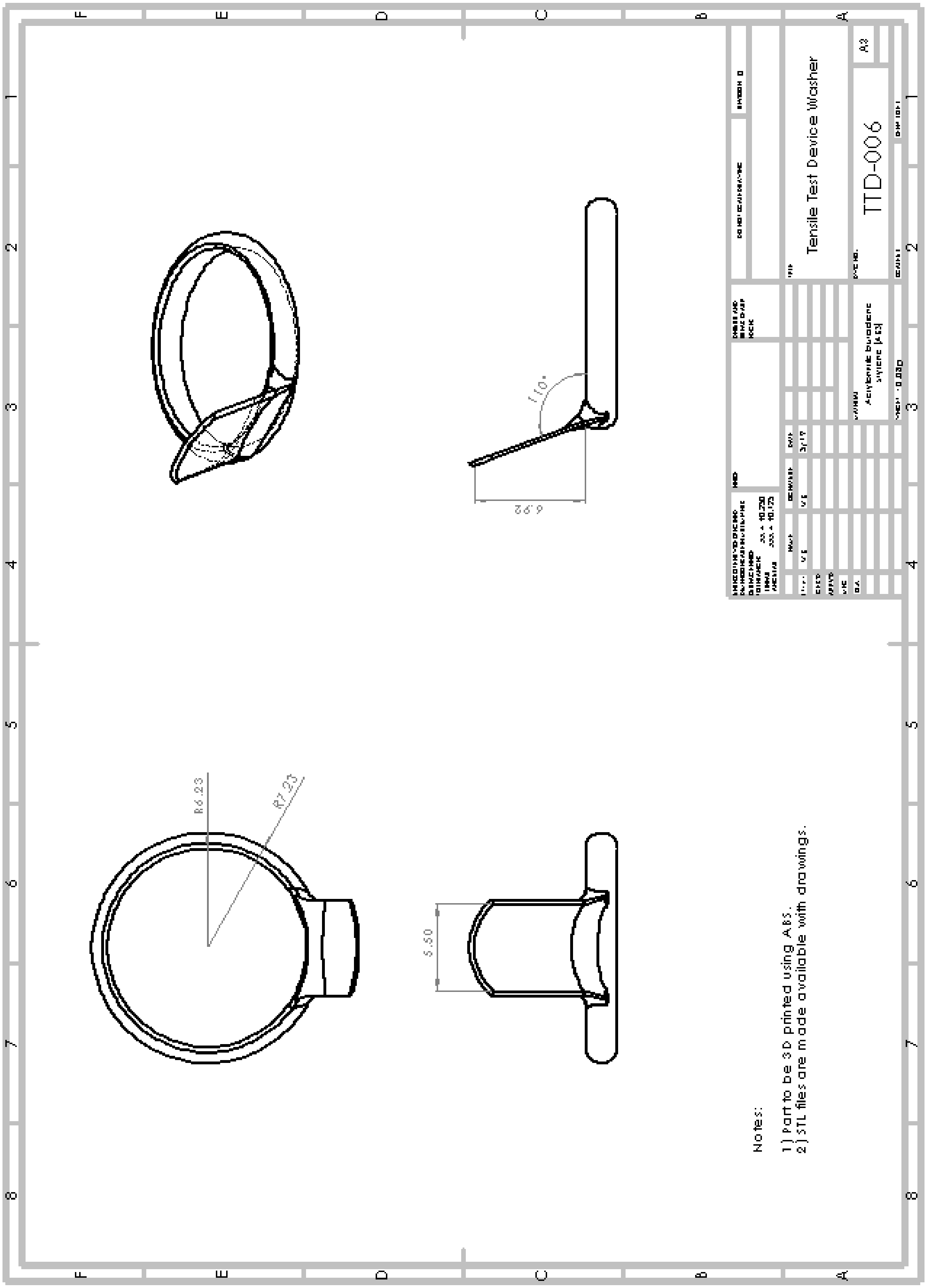

Tensile Test Device Button
TTD-003
A3
Acrylonitrile butadiene styrene (ABS)
Ø5.50 ↧15.00
10.00
5.75
25.25
R5.00
R4.50
Ø4.00 THRU
Ø10.00
Ø7.950
Ø6.950
R1.00
R2.50
Notes:
1) Part to be 3D printed using ABS.
2) STL files are made available with drawings.

D) Fixed End

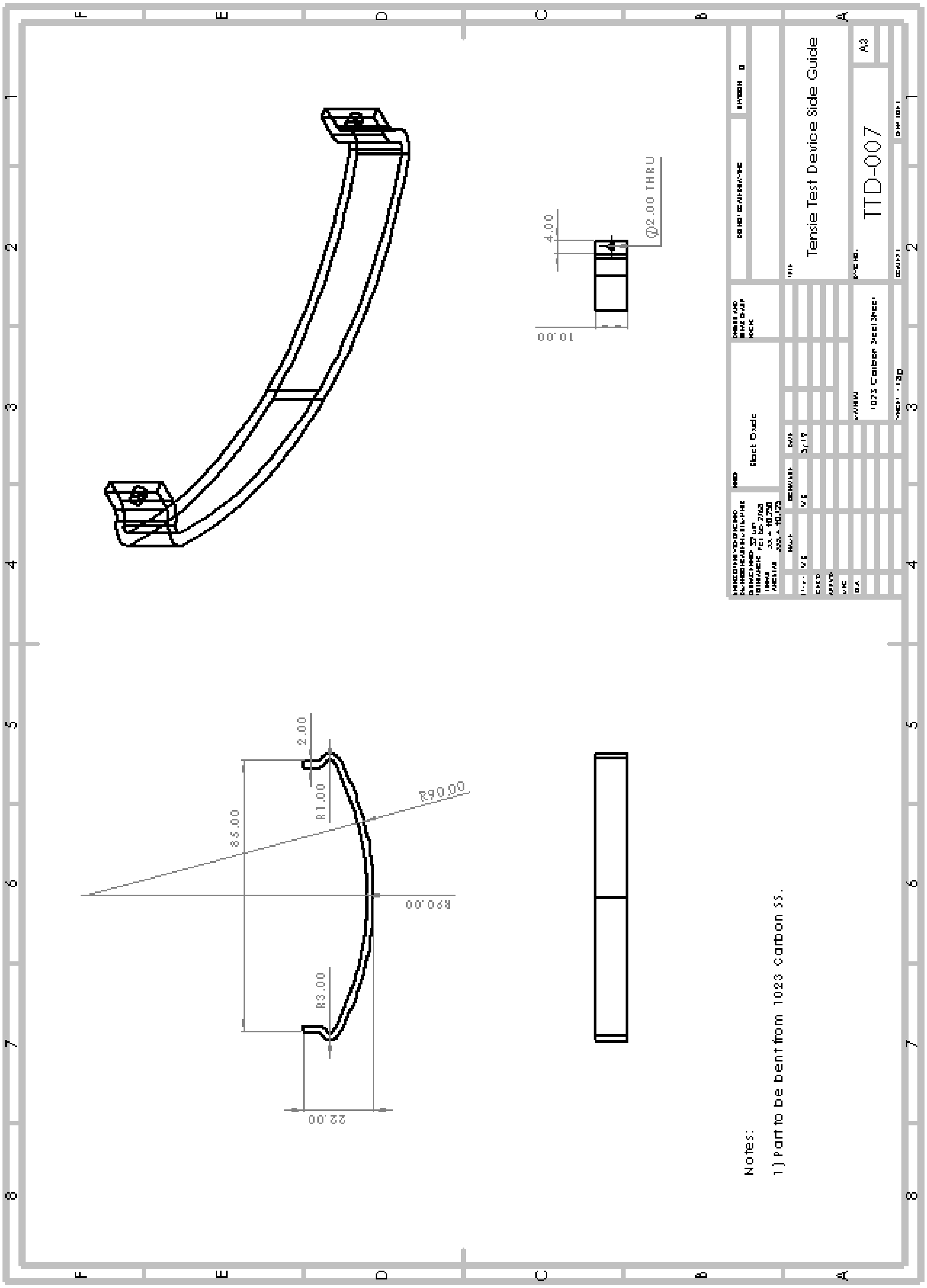


Tensile Test Device Fixed End
TTD-005
A3
AISI 1020 Carbon Steel
Ø13.950
1.500
10.000
18.31
Ø13.950
Ø13.95

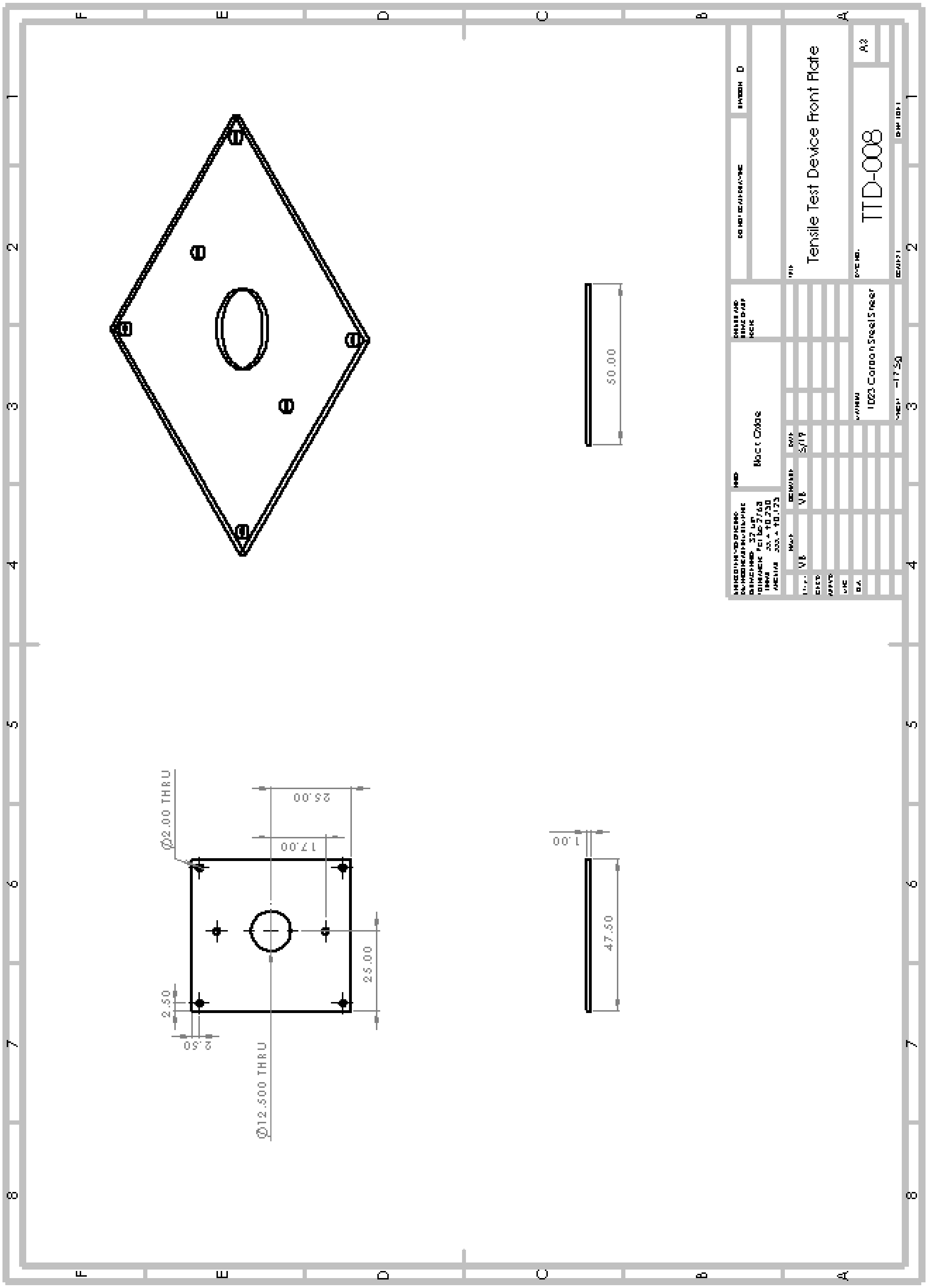
E) Washer


R6.23
R7.23
5.50
110°
6.92
Notes:
1) Part to be 3D printed using ABS.
2) STL files are made available with drawings.
Tensile Test Device Washer
TTD-006
A3
Acrylonitrile butadiene styrene (ABS)

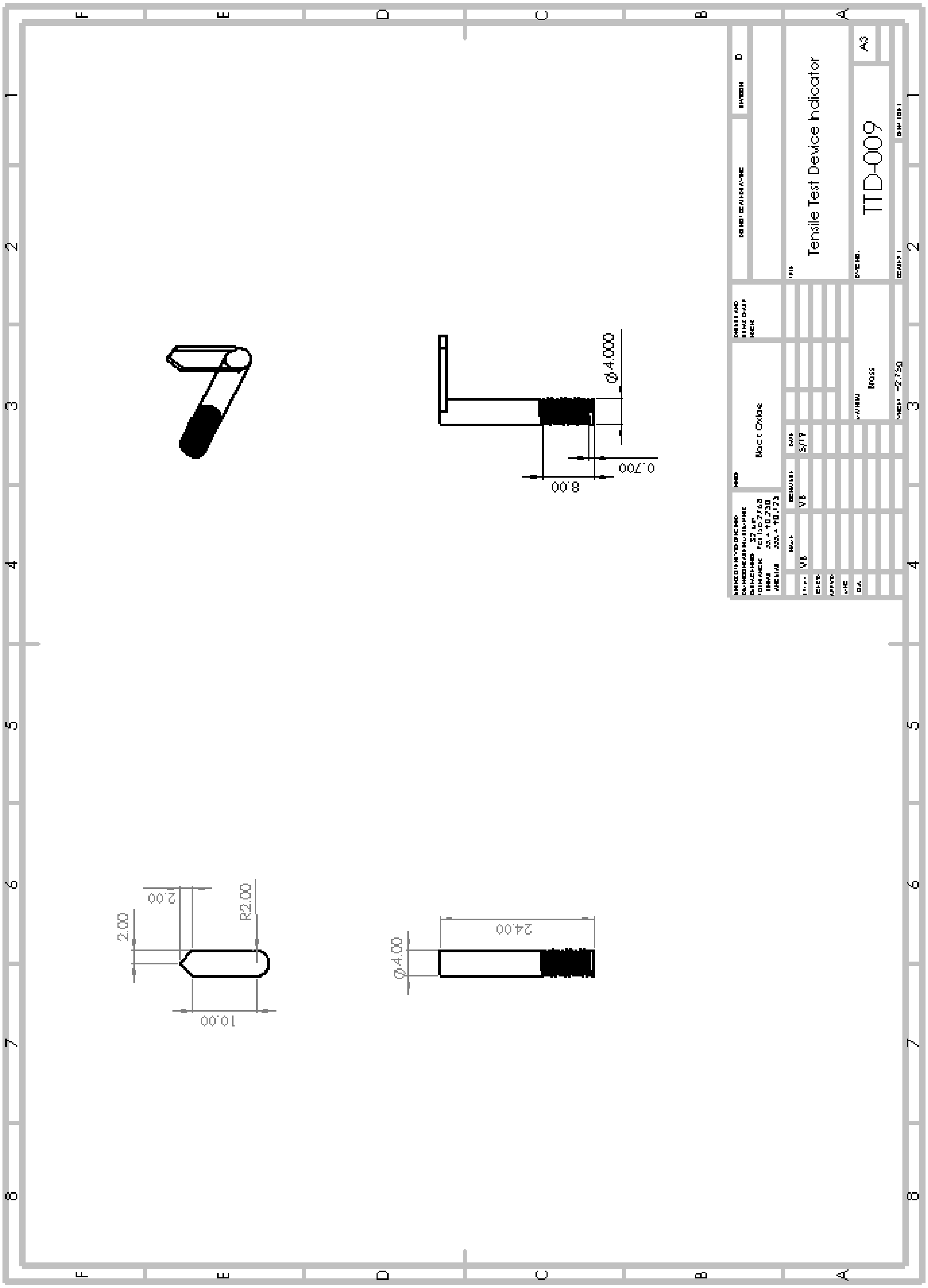
F) Side Guide


Tensie Test Device Side Guide
TTD-007
A3
1023 Carbon Steel Sheet
Ø2.00 THRU
4.00
10.00
R90.00
R1.00
R3.00
2.00
85.00
22.00
Notes:
1) Part to be bent from 1023 Carbon SS.

G) Front Plate

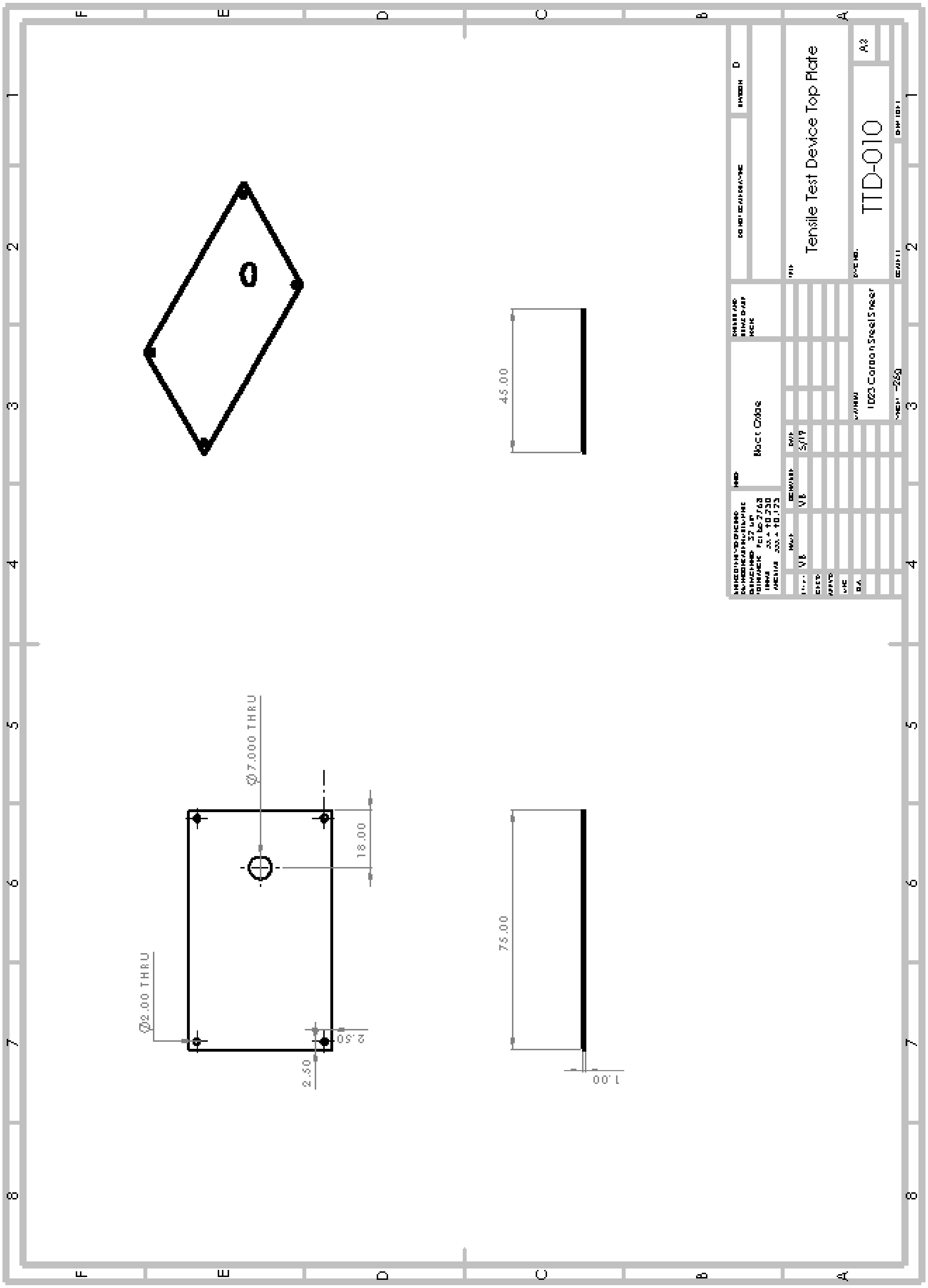


H) Indicator



Tensile Test Device Indicator
TTD-009
A3
Brass
Black Oxide
Ø4.000
0.700
8.00
24.00
Ø4.00
10.00
2.00
2.00
R2.00

I) Top Plate


Tensile Test Device Top Plate
TTD-010
1023 Carbon Steel Sheet
A3
45.00
75.00
18.00
Ø7.000 THRU
Ø2.00 THRU
2.50
1.00