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Materials Testing Machine: Design, Fabrication, and Assembly of a Benchtop Universal Materials Tester

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Abstract

The goal of this project was to prototype an inexpensive, easy-to-use, universal materials tester for hands-on learning in large undergraduate classroom settings. The project realized the design, fabrication, and assembly of a 26"x8"x7" benchtop machine able to apply tensile loads to round and flat specimens. The design is modular, with compression, wire, and bending test capabilities. Supplemental materials include a comprehensive operational package including CAD, CAM, and pertinent resources to implement the maintenance and development of current and future machines.

I. Introduction

A universal materials tester is a device commonly used to precisely measure the response of a material to tensile, compressive, or bending loads. It is used to generate stress-strain curves in order to document the material properties of a given specimen. Most industry-standard models come with a wide variety of features such as an integrated electronic user-interface panel, a control monitor with advanced programming and sensors, industry-grade extensometers, and more, thus making them expensive for teaching applications, and in some cases isolating the user from the physics of the testing process. The team's sponsor would like to offer the ability to use and learn from a basic materials tester to undergraduate students enrolled in materials science-related courses and projects in order to produce stress-strain curves and assist in the study of materials. As the capabilities of commercially-available testers are generally much greater than what would be required for classroom and demonstration use, this team was tasked with developing and manufacturing a design and prototype for materials testers for use by the school. This machine had to be capable of testing specimens from elastomers to mild steel in tension, compression, and bending while also fitting within the allocated $1,000 project budget (with the goal of producing another three to four machines with an additional $1,000).

II. Methodology

Material properties along with their understanding and documentation are a critical aspect of the functioning of modern infrastructure and society; and because of this inherent significance, materials testers have become an important tool within engineering-based industries since their inception in the late 19th century.

Although materials testers have made great advancements in their capabilities, their overall mechanics have stayed similar since their initial designs in the late 19th century [9]. These machines have key components such as a load frame, upper and lower crossheads with grips, and at least one lead screw or driving mechanism. When materials testers first came to be, the testing force was applied to a specimen through the use of a gear train and hand crank and was measured using a weighing table along with scales and a poise. Modern-day testers, such as a commercially available Instron machine, typically utilize either hydraulics or a motor for force application and often have an automatic digital readout for forces to plot stress-strain curves.

Materials testers generally have a fixed and a driving crosshead, with the load cell fixed to the driving crosshead to measure the forces applied during the test. The rotational motion of the lead screw translates the crosshead to apply force to a specimen; the force is measured by a load cell and then interpreted using a calibration factor via a microcontroller. Typically, materials testers have a vertical orientation where the crosshead translates vertically. When doing initial research, the team researched a vertically oriented testing machine, but determined to utilize a horizontal design after looking into various inexpensive horizontal testers for basic application; most benchtop, low-cost machines are only capable of testing in tension, mostly made of plastic, and some can be powered by a motor, generally utilizing an S-Type load cell. The team utilized a similar conceptual layout of fixed and driving crossheads and uniaxial linear motion rods along which the driving crosshead translates. The team planned to create a machine that was able to test a wider range of materials in both tension and compression as well as under bending.

All specimens for testing have standard sizes, ASTM and ISO providing the leading industry standards. These standards are generally proportional when changing the specimen sizes for both flat and round samples, focusing on the length to diameter ratio for round specimens and the width to thickness ratio for flat specimens. It was an objective of this project to test standard sample sizes.

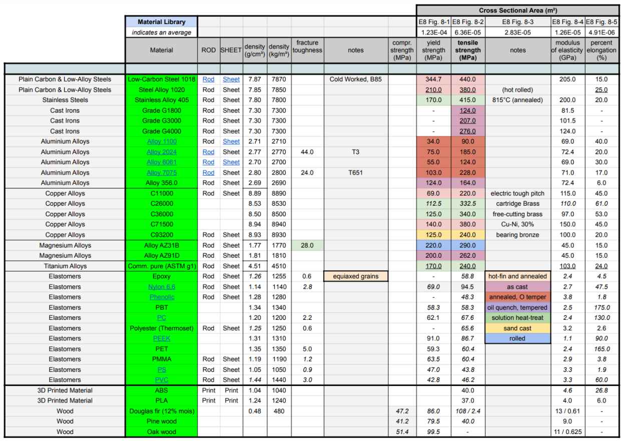
The primary constraint for this project was the cost of purchase, fabrication, and assembly materials and that played a large role in how the design process developed. It was determined that the best way to meet this cost constraint would be to minimize both the overall size and the complexity of the materials tester while still maintaining maximum functionality, efficiency, and overarching design objectives; a hand-operated materials tester with translating crossheads was thus chosen. Although this eliminated the possibility of testing high-strength metals and ceramics, the materials testing machine still maintained the ability to test materials with strength up to that of mild steel, while the simplicity significantly reduced cost. A materials chart, shown in **Table 1** and **Table 2**, was developed to determine the tensile strength of a wide range of materials to create a baseline minimum force that would need to be created by the machine. Research was conducted on the types and functions of materials testers and ASTM standards were used to develop a standardized sizing of round and flat test specimens that would allow the testing of materials with strength up to that of mild steel. From there, force constraints were set and work was started on designing a benchtop tensile and compressive materials tester that would be able to provide the specified load to break the desired range of materials; all while being able to test in tension, compression, and bending.

III. Design

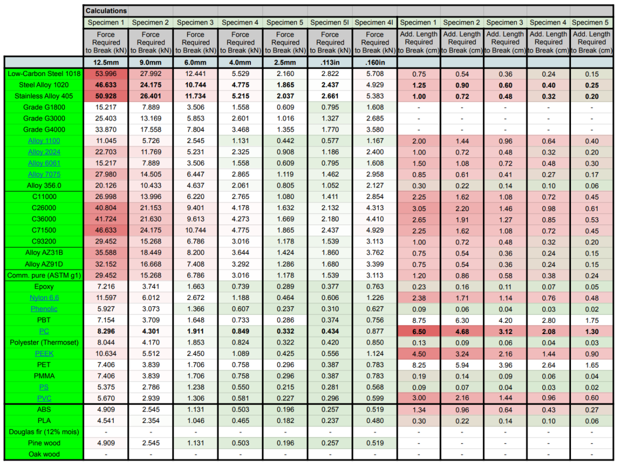
As mentioned during problem framing, the main financial constraint and objective that the team wished to meet was to create a machine that is at a much lower net cost than that of an advanced, industry-grade tester. The initial budget for the prototype was $1000.00. The goal was to be able to produce a total of four to five machines, with each machine for around $400.00. As far as size and overall dimension constraints for the project, the materials tester required a large enough lateral distance to allow for maximum material planned elongation and large enough frames and crossheads to allow for robust movement and rigidity. Based on sample sizing and planned elongation of the testing specimens, a minimum travel distance required is 6” for the standard sheet-sized flat samples and 3” for the subsize standard flat samples. In addition, the machine needed to be small enough to both fit on a benchtop and be able to be transported by cart.

In order to begin designing a tester, it was necessary to select which materials the machine could test. The ‘upper limit’ of the project was set at mild steel. This was because stronger steels and ferrous metals require relatively larger forces to break, increasing cost without any significant change in educational value. The ‘lower limit’ was set by polymers with a very high percent elongation. This was because polymers with a high ductility can stretch to five times their length or longer, thus requiring the machine to have a larger testing area. To select a library of materials, the team filtered standard materials from a standard introductory materials science textbook [2]. The team filtered these materials based on materials with tensile strength less than 300-400 MPa and materials having a percent elongation of less than 200% to meet the aforementioned criteria. This filtering was done initially with no regard to material cost and then commercially available rods and sheets of each respective ‘fit’ material were sourced. From this process, the team was able to select, out of select commonly available materials: two plain carbon and low alloy-steels, one stainless steel alloy, three cast irons, five aluminum alloys, five copper alloys, two magnesium alloys, one titanium alloy, eleven elastomer polymers, two 3D printed materials, and a minimum of three grades of wood. The data of the material library can be found in **Table 1** and **Table 2** below.

The following library details the selected general materials for the materials tester machine based on the criteria of having: a). Tensile strength less than 400 MPa, and b). Maximum percent less than 200% Note: This materials library can also be found in the project’s comprehensive operational package.



	Material Library								E8 Fig. 8-1	E8 Fig. 8-2	E8 Fig. 8-3	E8 Fig. 8-4	E8 Fig. 8-5
	indicates an average								1.23E-04	6.36E-05	2.83E-05	1.26E-05	4.91E-06
	Material	ROD	SHEET	density (g/cm³)	density (kg/m³)	fracture toughness	notes	compr. strength (MPa)	yield strength (MPa)	**tensile strength (MPa)**	notes	modulus of elasticity (GPa)	percent elongation (%)
Plain Carbon & Low-Alloy Steels	Low-Carbon Steel 1018	Rod	Sheet	7.87	7870		Cold Worked, B85		344.7	440.0		205.0	15.0
Plain Carbon & Low-Alloy Steels	Steel Alloy 1020	Rod	Sheet	7.85	7850				210.0	380.0	(hot rolled)		25.0
Stainless Steels	Stainless Alloy 405	Rod	Sheet	7.80	7800				170.0	415.0	815°C (annealed)	200.0	20.0
Cast Irons	Grade G1800	Rod	Sheet	7.30	7300				-	124.0		81.5	-
Cast Irons	Grade G3000	Rod	Sheet	7.30	7300				-	207.0		101.5	-
Cast Irons	Grade G4000	Rod	Sheet	7.30	7300				-	276.0		124.0	-
Aluminium Alloys	Alloy 1100	Rod	Sheet	2.71	2710				34.0	90.0		69.0	40.0
Aluminium Alloys	Alloy 2024	Rod	Sheet	2.77	2770	44.0	T3		75.0	185.0		72.4	20.0
Aluminium Alloys	Alloy 6061	Rod	Sheet	2.70	2700				55.0	124.0		69.0	30.0
Aluminium Alloys	Alloy 7075	Rod	Sheet	2.80	2800	24.0	T651		103.0	228.0		71.0	17.0
Aluminium Alloys	Alloy 356.0	Rod	Sheet	2.69	2690				124.0	164.0		72.4	6.0
Copper Alloys	C11000	Rod	Sheet	8.89	8890				69.0	220.0	electric tough pitch	115.0	45.0
Copper Alloys	C26000			8.53	8530				*112.5*	*332.5*	cartridge Brass	*110.0*	*61.0*
Copper Alloys	C36000			8.50	8500				125.0	340.0	free-cutting brass	97.0	53.0
Copper Alloys	C71500			8.94	8940				140.0	380.0	Cu-Ni, 30%	150.0	45.0
Copper Alloys	C93200	Rod	Sheet	8.93	8930				125.0	240.0	bearing bronze	100.0	20.0
Magnesium Alloys	Alloy AZ31B	Rod	Sheet	1.77	1770	28.0			220.0	290.0		45.0	15.0
Magnesium Alloys	Alloy AZ91D	Rod	Sheet	1.81	1810				200.0	262.0		45.0	15.0
Titanium Alloys	Comm. pure (ASTM g1)	Rod	Sheet	4.51	4510				170.0	240.0		103.0	24.0
Elastomers	Epoxy	Rod	Sheet	*1.26*	1255	0.6	equiaxed grains		-	*58.8*	hot-fin and annealed	*2.4*	*4.5*
Elastomers	Nylon 6.6	Rod	Sheet	1.14	1140	*2.8*			*69.0*	94.5	as cast	*2.7*	*47.5*
Elastomers	Phenolic	Rod	Sheet	1.28	1280				-	*48.3*	annealed, O temper	*3.8*	*1.8*
Elastomers	PBT			1.34	1340				*58.3*	*58.3*	oil quench, tempered	*2.5*	*175.0*
Elastomers	PC			1.20	1200	2.2			62.1	*67.6*	solution heat-treat	*2.4*	*130.0*
Elastomers	Polyester (Thermoset)	Rod	Sheet	*1.25*	1250	0.6			-	*65.6*	sand cast	3.2	2.6
Elastomers	PEEK			1.31	1310				91.0	*86.7*	rolled	*1.1*	*90.0*
Elastomers	PET			1.35	1350	5.0			59.3	*60.4*		*2.4*	*165.0*
Elastomers	PMMA	Rod	Sheet	1.19	1190	*1.2*			*63.5*	*60.4*		*2.9*	*3.8*
Elastomers	PS	Rod	Sheet	1.05	1050	*0.9*			*47.0*	*43.8*		*3.3*	*1.9*
Elastomers	PVC	Rod	Sheet	*1.44*	1440	*3.0*			*42.8*	*46.2*		*3.3*	*60.0*
3D Printed Material	ABS	Print	Print	1.04	1040					40.0		*4.6*	*26.8*
3D Printed Material	PLA	Print	Print	1.24	1240					37.0		4.0	6.0
Wood	Douglas fir (12% mois)			0.48	480			*47.2*	*86.0*	*108 / 2.4*		13 / 0.61	-
Wood	Pine wood							*41.2*	*79.5*	*40.0*		9.0	-
Wood	Oak wood							*51.4*	*99.5*	-		11 / 0.625	-



Calculations														
	Specimen 1	Specimen 2	Specimen 3	Specimen 4	Specimen 5	Specimen 5l	Specimen 4l	Specimen 1	Specimen 2	Specimen 3	Specimen 4	Specimen 5
	Force Required to Break (kN)	Force Required to Break (kN)	Force Required to Break (kN)	Force Required to Break (kN)	Force Required to Break (kN)	Force Required to Break (kN)	Force Required to Break (kN)	Add. Length Required to Break (cm)	Add. Length Required to Break (cm)	Add. Length Required to Break (cm)	Add. Length Required to Break (cm)	Add. Length Required to Break (cm)
	12.5mm	**9.0mm**	**6.0mm**	**4.0mm**	**2.5mm**	**.113in**	**.160in**					
Low-Carbon Steel 1018	53.996	27.992	12.441	5.529	2.160	2.822	5.708	0.75	0.54	0.36	0.24	0.15
Steel Alloy 1020	**46.633**	**24.175**	**10.744**	**4.775**	**1.865**	**2.437**	4.929	**1.25**	**0.90**	**0.60**	**0.40**	**0.25**
Stainless Alloy 405	**50.928**	**26.401**	**11.734**	**5.215**	**2.037**	**2.661**	5.383	**1.00**	**0.72**	**0.48**	**0.32**	**0.20**
Grade G1800	15.217	7.889	3.506	1.558	0.609	0.795	1.608	-	-	-	-	-
Grade G3000	25.403	13.169	5.853	2.601	1.016	1.327	2.685	-	-	-	-	-
Grade G4000	33.870	17.558	7.804	3.468	1.355	1.770	3.580	-	-	-	-	-
Alloy 1100	11.045	5.726	2.545	1.131	0.442	0.577	1.167	2.00	1.44	0.96	0.64	0.40
Alloy 2024	22.703	11.769	5.231	2.325	0.908	1.186	2.400	1.00	0.72	0.48	0.32	0.20
Alloy 6061	15.217	7.889	3.506	1.558	0.609	0.795	1.608	1.50	1.08	0.72	0.48	0.30
Alloy 7075	27.980	14.505	6.447	2.865	1.119	1.462	2.958	0.85	0.61	0.41	0.27	0.17
Alloy 356.0	20.126	10.433	4.637	2.061	0.805	1.052	2.127	0.30	0.22	0.14	0.10	0.06
C11000	26.998	13.996	6.220	2.765	1.080	1.411	2.854	2.25	1.62	1.08	0.72	0.45
C26000	40.804	21.153	9.401	4.178	1.632	2.132	4.313	3.05	2.20	1.46	0.98	0.61
C36000	41.724	21.630	9.613	4.273	1.669	2.180	4.410	2.65	1.91	1.27	0.85	0.53
C71500	46.633	24.175	10.744	4.775	1.865	2.437	4.929	2.25	1.62	1.08	0.72	0.45
C93200	29.452	15.268	6.786	3.016	1.178	1.539	3.113	1.00	0.72	0.48	0.32	0.20
Alloy AZ31B	35.588	18.449	8.200	3.644	1.424	1.860	3.762	0.75	0.54	0.36	0.24	0.15
Alloy AZ91D	32.152	16.668	7.408	3.292	1.286	1.680	3.399	0.75	0.54	0.36	0.24	0.15
Comm. pure (ASTM g1)	29.452	15.268	6.786	3.016	1.178	1.539	3.113	1.20	0.86	0.58	0.38	0.24
Epoxy	7.216	3.741	1.663	0.739	0.289	0.377	0.763	0.23	0.16	0.11	0.07	0.05
Nylon 6.6	11.597	6.012	2.672	1.188	0.464	0.606	1.226	2.38	1.71	1.14	0.76	0.48
Phenolic	5.927	3.073	1.366	0.607	0.237	0.310	0.627	0.09	0.06	0.04	0.03	0.02
PBT	7.154	3.709	1.648	0.733	0.286	0.374	0.756	8.75	6.30	4.20	2.80	1.75
PC	**8.296**	**4.301**	**1.911**	**0.849**	**0.332**	**0.434**	0.877	**6.50**	**4.68**	**3.12**	**2.08**	**1.30**
Polyester (Thermoset)	8.044	4.170	1.853	0.824	0.322	0.420	0.850	0.13	0.09	0.06	0.04	0.03
PEEK	10.634	5.512	2.450	1.089	0.425	0.556	1.124	4.50	3.24	2.16	1.44	0.90
PET	7.406	3.839	1.706	0.758	0.296	0.387	0.783	8.25	5.94	3.96	2.64	1.65
PMMA	7.406	3.839	1.706	0.758	0.296	0.387	0.783	0.19	0.14	0.09	0.06	0.04
PS	5.375	2.786	1.238	0.550	0.215	0.281	0.568	0.09	0.07	0.04	0.03	0.02
PVC	5.670	2.939	1.306	0.581	0.227	0.296	0.599	3.00	2.16	1.44	0.96	0.60
ABS	4.909	2.545	1.131	0.503	0.196	0.257	0.519	1.34	0.96	0.64	0.43	0.27
PLA	4.541	2.354	1.046	0.465	0.182	0.237	0.480	0.30	0.22	0.14	0.10	0.06
Douglas fir (12% mois)	-	-	-	-	-	-	-	-	-	-	-	-
Pine wood	4.909	2.545	1.131	0.503	0.196	0.257	0.519	-	-	-	-	-
Oak wood	-	-	-	-	-	-	-	-	-	-	-	-

Table 1: Material Library - Properties Based

Table 2: Material Library - Calculation Based

Test specimens were based on the standards established for tensile and compression testing (ASTM E8/E8M - 16a and ASTM 9 - 09, respectively). For compressive specimens, the standards specified the usage of two flat bearing blocks for sample mounting or the usage of one bearing block and a spherical seated bearing block to allow for additional rigidity during compression. The ASTM E9 - 09 standard also recommends setups for compressive testing jigs, apparatus, and sample sizes including thin sheets and cylinders.

The ASTM E8/E8M - 16a standard for the tensile testing of metallic materials is a detailed and intricate documentation and includes various types of adaptive round, flat, and wire test specimens, a wide range of adaptive grips, and the interpretation of test data. For this project's scope, the machine was constrained to be able to test both round and flat samples, with the room to test wire specimens. For round samples, the team selected the specimens 3, 4, and 5 as small-size specimens proportional to the standard specimen [5].

These were smaller cross-sectional round samples and allowed for the toughest tensile material to break with a required maximum force of around 2.16kN, determined via the maximum required force for the strongest material in the materials library, something that is very achievable with a small-budget design. For flat samples as standardized by ASTM E8, the thickness and width of each 'dogbone-shaped' sample are variable, allowing for the samples themselves to range within a variety of materials and cross-sectional areas.

The key design concept behind this materials tester was modularity. This allowed the project to adapt and evolve with ease as design decisions were made, changed, or removed - and also allowed for further future adaptations and changes. The modularity of the design includes the adaptability of test fixtures and grips, load cells, fixturing of the driving crosshead to the lead screw, and the driving of the lead screw itself.

For the most part, the compressive capabilities of this project's machine were designed to be a function of its tensile capabilities. This initial focus on tensile testing was based on the fact that tensile properties and the tensile testing of materials are much more well documented than compressive properties. Additionally, tensile testing generally requires lower forces than compression testing. Allowances were also made for wire testing and three-point bending. Ultimately, based on the modularity of the tensile capabilities of the machine, the integration of other means of mounting and testing can follow in future design iterations.

This project was intended to provide the sponsoring institute with materials testing machines that are compact and cheap enough that multiple working models could be used in a hands-on undergraduate lab or classroom. A group of students must be able to produce a fairly accurate and representative stress-strain curve if given a test specimen and one of these machines. It was determined that the machine should not require more manual input via a crank to operate than an average person could easily provide. The output data should equally be easy to compile, view, export, and interpret. Additionally, the machine should be able to be easily operated and serviced with simple, standard hand tools.

IV. Implementation

In the end, this project resulted in an average cost per machine of roughly \$520 subject to available materials, shipping, and other factors. Note that \$520 reflects the average cost between the team's raw price per assembly and the price paid per assembly, as a lot of assembly materials can be found or are already available in many academic and STEM settings.

As part of the implementation and realization of the machine, the project produced a comprehensive operational package accessible to researchers, students, and machine users. This included organized CAD and CAM folders of the machine and its parts and detailed instructions on how to fabricate them, a code folder of calibration and operational code for the load cell, a folder of pertinent ASTM standards, a formal bill of materials with market links, an instructions, operations, and maintenance manual, this report, the machine's materials library with properties, and finally custom-fitted standard round specimen sizes. The entirety of the machining processes for the materials tester was completed on-site at WPI using the machinery available in Washburn Shops. Detailed stock, machining, and operation callouts including completed Esprit files for every critical part can be found within the operational package's comprehensive CAM folder.

V. Results

The materials tester prototype was unsuccessful in breaking the produced round specimen of mild steel. While the crossheads were able to translate freely while unloaded, when the specimen was attached, the crosshead that was not corrected with ball bearings replacing the original bronze bushings was binding against the linear motion rods. Another set of ball bearings have been ordered with the hopes of remedying the issue entirely for all moving crossheads. The team believes that replacing the other three (other half) bronze bearings embedded in the remaining middle crosshead (LeftMidCrosshead) with ball bearings will entirely prevent any binding issues as experienced earlier. While the specimen did not break, the machine was successful in applying a significant load to the specimen which may have been strong enough to break a weaker polymer specimen had one been fabricated and available.

The original objective of the materials tester was to be able to test both flat and round specimens in tension, and different specimens in compression as well as complete three-point bending tests and wire tensile tests. The grips for the three sizes of round specimens were completed, although slight changes in fixturing bolt lengths might be required to improve ease of use. Due to the length of time and detail in fabrication needed to machine the parts, only two of the tool steel grips were produced. Material is available to produce more, and the CNC programming to produce more is also completed. After all the tool steel grips are completed it is recommended to heat treat the surface of the grips before they are used for testing. The resulting increase in hardness should prevent damage while testing and increase part life. The wire grips, the three-point bending grips, and the compression grips were not produced, however detailed CAD files for the models are contained in the operational package for future manufacturing and production. The load cell was calibrated with a simple setup utilizing a vice, string, and a 10N spring scale. Varying known forces were applied in both tensile and compressive directions, and the calibration factor was then recorded. After, the calibration factors were incorporated into the operational code and package as tested.

During testing the load cell was successful in providing a force readout that increased as the load was applied to the specimen. The data produced was not incredibly useful in its current state as the machine only produced force values with respect to time. It is therefore necessary to incorporate a way to measure strain and elongation so that useful curves such as a stress-strain curve can be produced.

VI. Discussion and Broader Impacts

The lessons learned from the prototype have led the team to propose the following recommendations to be incorporated in the future development of the machine. An important development would be the addition of a strain gauge or basic extensometer to measure strain. The load cell allows for the recording of stress in the sample, so if the device could also measure strain it would be able to generate a stress-strain curve. Also, the code could be packaged into a stand-alone application so that the Arduino IDE is no longer required. The device could even be given a small interface so an entirely separate computer or laptop isn't required.

Another way to improve the machine would be to add a second lead screw connected by a chain and sprocket. While this would increase the cost of the device, one of its most significant issues right now is the crossheads rotating instead of translating due to the imperfections in the straightness of the lead screw, causing the crossheads to bind. If the machine were to be made wider or taller and a second lead screw installed so the samples and load cell were between the two lead screws, then the crossheads would no longer be attempting to rotate and exert unwanted force on the linear motion rods. While it would increase the number of parts, this would make the device much more reliable, accurate, and easy to use. The crossheads could simply 'float' along the lead screws and actually reduce the number of structural linear motion rods as more lead screws are introduced. Another way to potentially combat the issue of the crossheads deflecting would be to get additional or thicker linear motion rods to stabilize any bending or deflection across the face of the crossheads. While the current 1/2" rods are stiff on their own, they bend quite easily when being driven by such a large lead screw. More linear motion rods located near the bottom of the crosshead would help combat this issue.

Another recommendation would be to make the crank handle longer to generate more torque. Note that this added torque would not be a solution to the binding, the ball bearings are the recommended solution to that; added torque would simply improve user-friendliness and ease of use. The team's current design was limited by the location of the lead screw and the fact that the height of the lead screw off the table or operating surface would dictate the maximum radius of the crank such that it (or the user's hands) wouldn't make contact with the table during rotation. Adding a motor to rotate the lead screw at a constant rate could also help user-friendliness, despite adding to the cost of the machine; this could also help with the stabilization of rotations versus time to help determine accurate time-based strain values to correlate to exact stress values. There is room for added costs, so a motor may be a worthwhile investment, especially when considering the manufacturing times and costs of the crank being eliminated (roughly -$28.71).

There are also a few smaller changes that should be made for easier operation and to improve functionality. The smallest round sample holes in the crosshead should be relocated, allowing all the hardware to test multiple sizes of round specimens to be mounted at the same time, saving time to interchange parts and samples if testing multiple round specimens. The team also had difficulties when securing round specimens. After looking through why this is, the team found that if the nuts holding the round specimens were not simultaneously running on the studs from the crosshead, they would be much easier to install. Another change is in the rectangular frame brackets. If they were adjusted to be an "L"-shape and not extend to the lower level of the 80/20, the mounting feet could easily be loosened and removed to be reused for scenarios when the machine is operated vertically (if the feet were fabricated). This would remove the necessity to have extra frame brackets needed for this purpose. In addition, the length of the round sample mounting bolts could be increased to be able to secure more threads on the round specimens.

Overall, this project has the potential to be a very useful tool in engineering education applications, thus the realm for changes to adapt and develop this materials tester can be vast due to the machine's modularity and detailed documentation over the course of the academic year.

By developing a means to inexpensively produce an easy-to-use universal materials tester with basic CNC machinery and hand-tools entirely from scratch, this project has paved the way to increase the accessibility of such devices in classrooms, labs, and workshops. Using the machine, undergraduate students in mechanical and materials engineering classes will be able to gain a hands-on understanding of how the stress-strain curves in their textbooks were produced. If a lab or workshop requires material testing, but the machine's ability to demonstrate the processes are prioritized over high accuracy, this machine is an extremely cost-effective and efficient alternative to the very expensive materials testing machines already on the market at a very affordable price of around $520 per machine. This machine also has a far lower space requirement and hardware - while common commercial materials testers usually have to be installed in a lab, the device fits on a standard benchtop work surface and can be removed and placed into storage when not in use. Ultimately, this materials tester developed over the course of this academic year not only provides value in terms of producing tangible material property data, but also cultivates the overall learning and hands-on approach towards experimentation within the mechanical and materials engineering curriculum and scholarship.

VII. Conclusion

In this major qualifying project an inexpensive benchtop universal materials tester was designed, fabricated, and assembled entirely from scratch. The design process involved detailed CAD and tolerancing, with multiple design iterations. The machine was manufactured using CNC and manual machinery, and this included creating and executing fabrication programs in Esprit as well as many assembly tweaks and troubleshooting processes. The materials tester prototype was completed and was able to apply a tensile load to either a round or a flat specimen, and the loads could be measured with the load cell. However, a bent lead screw caused the crossheads to bind, so the round steel test specimen could not be loaded to its fracture stress. Recommendations were provided for resolving this defect in future iterations.

A user manual was written for future users and includes maintenance instructions and code needed to operate the load cell. Detailed documentation has been provided for future teams, including CAD and CAM files, with insights on design improvements for a beta prototype. The design is modular, and future teams have the ability to incorporate compression, wire, and bending capabilities.

Ultimately, the team believes that continuations and future developments on this materials tester possess a significant capacity to foster and inspire valuable classroom learnings within pertinent STEM disciplines at the sponsoring institution and the broader academic settings beyond for years to come.

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