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The Sagan Research Project for Exploring Statistical Parameters of Typical Mechanical Properties

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Abstract

The involvement of undergraduate students in research is very important for engineering education. Research can not only significantly enhance student engagement and enrich student learning experience, but it is also useful as a tool to enhance undergraduate engineering education. However, it is a big challenge for a small teaching institution to do this because most of the faculty don't have funded research projects, their primary job is teaching a full load. In addition, some frequently raised questions from lectures or labs could be used as research projects for undergraduate students in the teaching institute. Tensile test labs were used for obtaining stress-strain curves in the MECH2500-Mechanics of Materials course to observe material behaviors under tensile load and to obtain some typical mechanical properties of materials, such as Young's modulus, yield strength, and ultimate strength. Some undergraduate students in mechanical engineering majors frequently asked why the results of the same materials under the same type of equipment and same test procedure were different when they conducted the tensile tests on an Instron universal test machine. In spring 2016, to help the students find answers by themselves, a research project was initiated with heavy student involvement to explore statistical parameters of typical mechanical properties. This team includes 3 faculties from two different departments, one staff from the Strength Test Center and several students. After one-year's work, 4 sets of test data had been obtained by the student research team and can be used to answer their questions. This paper will describe and present in detail the research activities. In the research, students implemented what they learned in classrooms to the research, designed and manufactured specimens, created test procedures, ran tensile tests, wrote test reports and conducted data analysis. Through the research, students gained hands-on research experience and had a better understanding of the mechanical properties and their statistical descriptions of materials. Some students showed great interest in doing research in future. Through this research, it was shown that some fundamental common questions or topics raised by the students during their courses can be used as undergraduate research projects. Students benefit greatly from such research projects.

1. Introduction

The mechanical properties of materials gathered from tensile tests are critical strength data for mechanical design. In the course MECH2500- Mechanics of Materials, tensile tests were conducted on an Instron Universal Testing machine to obtain a stress-strain curve. From the curves, typical mechanical properties such as Young's modulus, yield strength, ultimate strength could be obtained [1]. Frequently, students ask two questions: "Why are there some differences between the mechanical properties obtained through their tensile tests and the book values?", and "Why are there some differences among the obtained mechanical properties of the same material from different lab groups even though they used the same standard specimens of the same material and the same test procedure on the same type of Instron machines?". These questions can be easily answered by faculty and would be studied in some more advanced courses. However, it could be answered by themselves through a small research project. This was a great topic for a student research project because these undergraduate students can certainly conduct it. When students find answers by themselves through their own research, their understanding of topics would be enhanced.

Undergraduate research is gaining widespread recognition in engineering education. The list of some key benefits of undergraduate research is: to enhance student engagement in the program; to enrich student learning experience; to excite students about research; to enhance retention of students in the program; to improve engineering education and graduation rates of engineering students [2-6]. For any research project, there is a requirement of funding. For many large research institutions, it can be very easy to invite undergraduates to participate in their funded research because they have lots of existing funded projects. For smaller teaching institutions, the need for some funding is a big burden on faculty. Wentworth Institute of Technology is a small private teaching institution. Most faculty do not have funded projects as they are hired as full-time teaching faculty. However, since 2015, the institute has provided "The Sagan faculty fund grant program" for faculty, which coherently supports the institutes No#1 Strategic Priority "Creating transformational educational experiences" with the three detailed objectives "Achieve superior results with our students"; "Expand learning opportunities"; and "Integrate externally-collaborative, project-based, interdisciplinary curricula for learning across the institute". With support from the Sagan faculty fund grant program, students' research project which are focused on fundamental concepts or topics related to the courses become possible in small private teaching institution.

In spring 2016, with the support from the Sagan faculty fund grant program, a research team was formed to explore statistical parameters of typical mechanical properties, which was a small part of the research project of exploring statistical models of metal fatigue strength. This team includes 3 faculties from two different departments (mechanical engineering department and civil engineering department) and one staff from the Strength Test Center and most importantly several students. After one year with the involvement of 6 part-time student research assistants and 2 co-op student research assistants, the research project was successful and a large amount of test data on mechanical properties was obtained, and can be used to answer their questions, and described the statistical parameters of the mechanical properties. Through their research, students gained hands-on research experience, implemented what they learned in the classroom to the research, designed and manufactured specimens, created test procedures, ran tensile tests, wrote test reports and conducted data analysis.

This paper will describe and present in detail the research activities including team management, research planning, searching test standards, designing standard test specimen, designing necessary fixtures for manufacturing, creating manufacturing CNC (Computer Numerical Control) programs, manufacturing specimens, designing & manufacturing necessary tools for testing, creating test methods & procedures, running tests and conducting data analysis and writing technical reports.

2. The Sagan research project activities

Our institute is a teaching institution. Students learn through class and labs, gain hands-on experience by doing different class design projects. However, students had little chance of being involved in research projects because most faculties have a full teaching load assignment and little funding for research. Since the Sagan faculty fund grant program was initiated in 2015, we have some chances to invite some students to participate in the research project on fundamental concepts or topics related to the courses. The project presented in this paper was to explore statistical parameters of typical mechanical properties, which was a small part of the research project of exploring statistical models of metal fatigue strengths.

The main criterion for hiring students was that the student must be a full-time student with an average GPA over 2.5 so that the research project does not become a burden on their academic performance. At the beginning of each semester, the job posting was sent to all mechanical students. At the end of the second week, two undergraduate students were hired and had the job title of a part-time research assistant and worked on the research project for 6 hours per week at the pay rate of $11 per hour. They worked on the research project for approximately 12 weeks per semester. For each semester, different students were hired to let more students get involved in the research. Wentworth is a 100% cooperative education school. All students must do 2 semesters of co-op. Sometimes, a full-time co-op student was hired to work on this project when he or she failed to land a co-op job in a company during their designated co-op semester.

In this research project, the role of faculty and staff was that of facilitators and advisors for these part-time research assistants. The common settings for this research team were: (1) in the first three weeks, each student was asked to write a summary report about the mechanical properties of materials and related testing; (2) there was a weekly meeting between the faculty and students,; (3) the co-op students and part-time research assistants were required to complete all the research activities from planning, manufacturing, testing and data analysis, and (4) at the end of the semester, each student was asked to write a summary report about their research work during the entire semester. Following are the description and analysis of the Sagan research project activities for exploring the statistical parameters of typical mechanical properties.

2.1 Making a tentative research plan

At the beginning of the project, the student research assistants had some misconception about the research because they had no research experience. They simply said that conducting a lot of tensile tests would obtain enough data for exploring statistical parameters of typical mechanical properties. They said this because they did the tensile tests with the provided specimen and test procedure in the course MECH2500-Mechanics of Materials. When students were asked two questions: (1) How to make this data useful for others or to be accepted by others? and (2) How to make sure that the test data is reliable? the student research assistant realized that there was some difference between a class lab and a research project.

The entire team worked together to make a tentative research plan which included 5 main tasks: (1) Design the tensile test specimen, (2) Manufacture the tensile specimen, (3) Develop the tensile test procedure, (4) Run the tensile tests and (5) analyze the test data and write test reports. The concise description and explanation of the main tasks and corresponding activities are as followings:

(1) Design the flat plate tensile test specimen

The manufacturing capability of the shear machine in our school is 12-gauge of steel plates and the 10-gauge of aluminum plates. The whole team agreed to run the tensile tests on two metal materials, cold rolled A1008 steel and 6061-T6 aluminum plates. To have the test data be useful or to be accepted by others, students realized that the test specimens must be designed per ASTM (American Society for Testing and Materials) standard.

(2) Manufacture the tensile specimen

To have the data be statistically significant, the sample size of the tensile test specimen should be more than 30 samples. It was decided that the sample size of the specimen of the same materials would be 50. After discussion, the team agreed that some controls for manufacturing tensile specimen must be provided to make all specimens the “same” within the acceptable dimension tolerances.

(3) Develop tensile test procedure

The tensile tests were run on an Instron universal test machine, which is controlled by Instron’s Bluehill® program. To make the test data reliable, proper test procedures were required to be created and tested.

(4) Conduct tensile tests

To make the test data reliable, student research assistants were asked to run enough trial tests to identify what needed to be done for accurate test results and were familiar with each step and each device before they recorded actual tensile test data on the specimens.

(5) Analyze test data

From each tensile test, the goal was to collect four typical mechanical properties including Young’s modulus, yield strength, ultimate tensile strength and the percent elongation. It was noticed that the analysis on the ultimate tensile strength and the percent elongation was easy because the unique test data were obtained through the tensile tests. student research assistants needed to be trained and had some discussions for how to conduct the data analysis for Young’s modulus and the yield strength because they might get quite different results from the recorded raw data of the same tensile test.

2.2 Design the sheet-type tensile test specimen

Student research assistants were guided to search the information for the tensile specimen through the ASTM standards. The tensile specimen in the Sagan research project was a sheet-type flat specimen with a thickness of 10-gauge for aluminum and 12-gauge for steel. After discussions, student research assistants recognized the difference between the flat plate specimen and the sheet-type flat specimen. They realized that the thickness of the sheet-type flat specimen is equal to the thickness of the sheet plate. There is no need to manufacture in the thickness direction. The dimensions of the sheet-type tensile specimen are specified by ASTM E8/E8M-15a [7]. The tensile specimen in the Sagan research project is shown in Figure 1 and is specified per ASTM E8/E8m-15a.

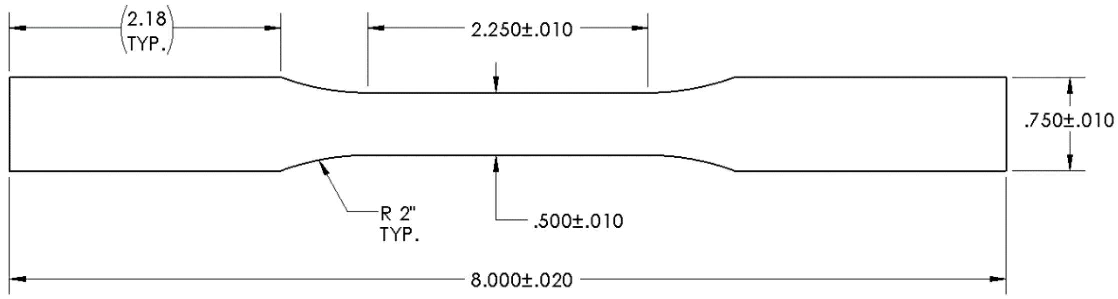
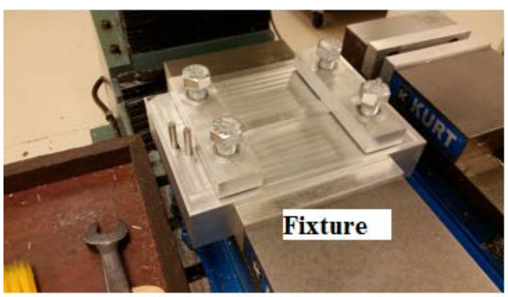


Figure 1: sheet-type tensile specimen with the thickness of the sheet plate

2.3 Manufacture the tensile specimen

Mots of student research assistants had taken several manufacturing courses such as MANF1000-manufacturing processes I, and MANF2000-computer aided manufacturing. They got the help from their manufacturing faculty and used the knowledge learned in the courses to design the manufacturing routine including fixtures and to manufacture the tensile specimens. To make the tensile specimens consistent with the acceptable tolerances, students developed and documented the manufacturing routing for manufacturing the specimen. The manufacturing routing for manufacturing sheet-type tensile specimen was: (1) Shear the sheet into rectangular plate per the drawing with a machine allowance 3/16", (2) Deburr rectangular strip for the purpose of safety; (3) Mill the edges of the rectangular strip to the required dimensions and (4) Insert the rectangular strip into the specially designed fixture and use CNC program to mill the rectangular strip into the sheet-type tensile specimen with the required final dimensions. The photo of the fixture for manufacturing the sheet-type tensile specimen is shown in Figure 2. The CNC program with the fixture had effectively and accurately manufactured high-quality sheet-type specimen for the Sagan research project.



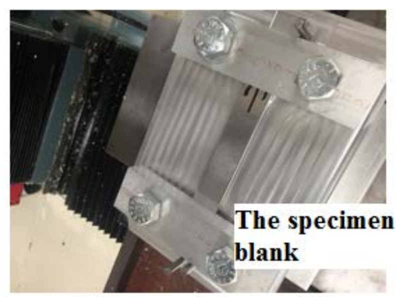


Figure 2: photos of the fixture for the sheet-type tensile specimen

2.4 Develop tensile test procedure

The whole research team worked together to study the Bluehill software, which is used to create the test method (control program) for the tensile tests. To get more accurate data for Young's modulus, an extensometer was used for the tensile tests. The setup of the tensile test is shown in Figure 3. In our test procedure and the test method, when the strain reached a strain 0.0200, the extensometer was removed in order to protect the extensometer. After the extensometer was removed, the tensile test continued until the tensile specimen was broken.

Figure 3: sheet-type tensile test with extensometer

2.5 Conduct tensile tests

The tensile test was controlled by the test method (control program) per the specified test procedure. To obtain accurate test results, the human factor should be as small as possible. When the specimen was placed between the top and bottom grips, it is required that the specimen is installed vertically. If not, the loading on the specimen will not be a pure axial load. To install the specimen vertically, an auxiliary block was designed and manufactured to make the specimen vertical as shown in Figure 4. The percent elongation of a tensile specimen is the percentage of the deformation change per 2" gauge lines. To draw the 2" gauge lines, an auxiliary gauge length block with length $2.000 \pm 0.001''$ was also designed and manufactured and used to mark two lines on the tensile specimen before testing as shown in Figure 5. The length between the out-edges of two marks would be $2.000 \pm 0.001''$. After the specimen was broken and was re-matched, the distance between these 2"- gauge lines were measured and used to calculate the percent elongation.

Figure 4: auxiliary block for vertically assembling the specimen

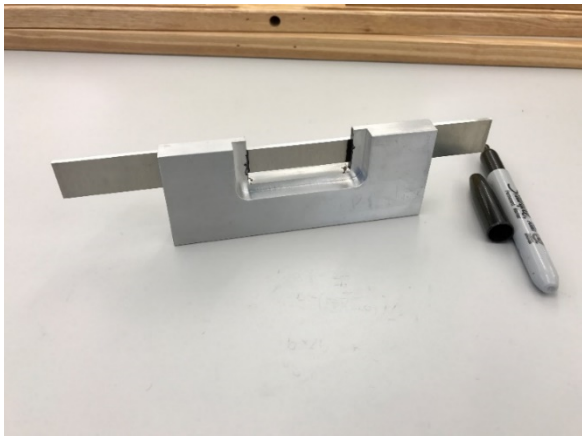


Figure 5: auxiliary block for 2” gauge length

2.6 Data analysis and results

The aluminum sheet-type tensile specimen was made from 10-gauge 6061-T6 sheet plate. The steel sheet-type tensile specimen was made from 12-gauge cold rolled A1008 steel sheet plate. For each material, 50 specimens in the L- (longitudinal) direction, and 50 specimens in the T- (transverse) direction were manufactured and tested. For each test, 4 mechanical properties [7] including the percent elongation, yield strength, ultimate tensile strength and Young’s modulus were obtained through data analysis. For each set of data, the general statistical parameters including the mean, standard deviation and the coefficient of the variation [8,9] were analyzed based on the experimental data.

During data analysis, students realized that it was very easy to calculate the ultimate tensile strength and the percent elongation because of the unique data collected per tensile test. However, the data analysis for Young’s Modulus and yield strength was difficult for them. As an example, Figure 6 shows one stress-strain curve for a 6061-T6 specimen. The stress was calculated by using the tensile load over the original cross-section. The strain was directly obtained from the extensometer. In Figure 6, the right vertical line was caused by removing the extensometer when strain reached 0.020. To get a proper value for Young’s modulus, students needed to pick the section of data for calculating Young’s modulus. After a few practice attempts, they could get proper values per tensile tests. However, they had a very tough time determining the yield strength. The students were not sure how to determine the yield strength from the stress-strain curves such as Figure 6 which was obtained by using the extensometer. Then students then tried to use the load vs the extension of the specimen between the two grips as shown in Figure 7. The yield strength could be the first spike in Figure 7. But this view was a quite different view than is typically described in textbooks [8, 9]. The entire team worked on how to determine the yield strength. Finally, it was found that the load vs time was the best curve to determine the yield strength as shown in Figure 8. Through this data analysis, students had a much better understanding of mechanical properties.

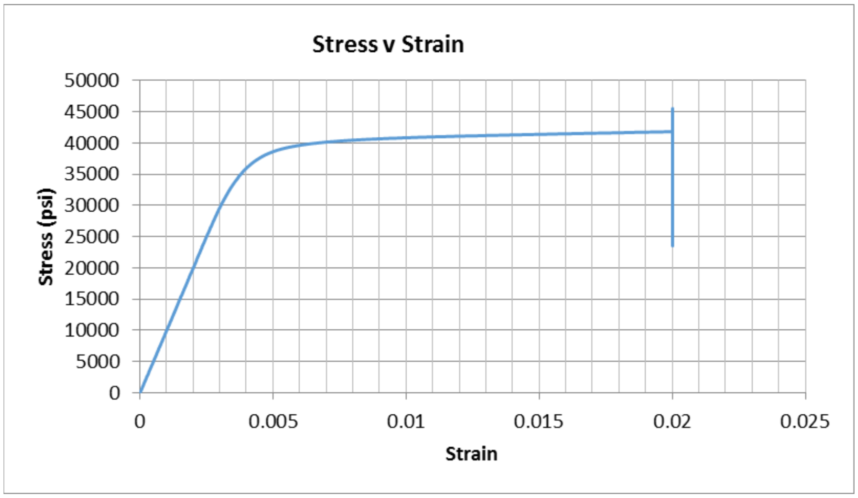


Figure 6: one stress-strain curve of a 6061-T6 tensile test

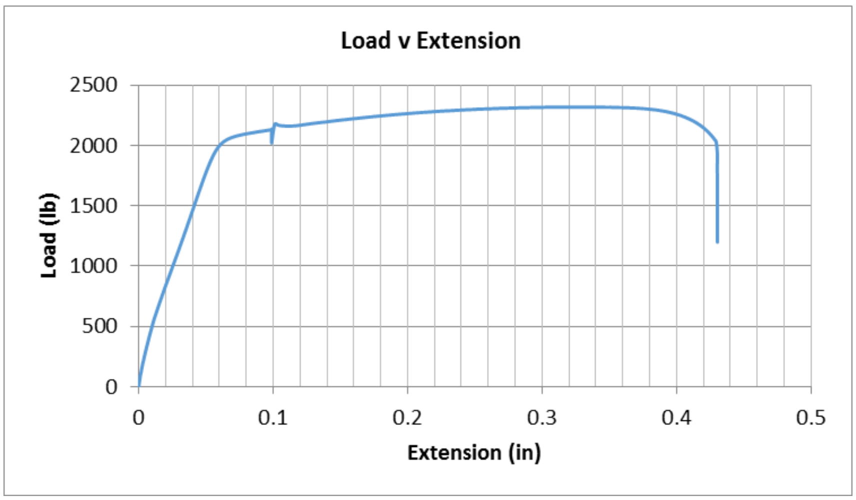


Figure 7: one load vs extension of a 6061-T6 tensile test

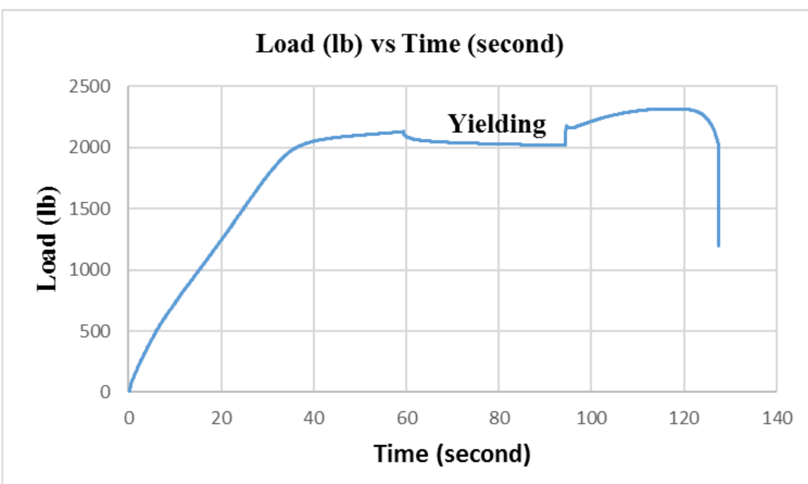


Figure 8: the load vs time of a 6061-T6 tensile test

The raw test data of the mechanical properties of the aluminum specimen in the L- direction are shown in Appendix table 5-1 and the corresponding statistical parameters are shown in Table 1. The raw test data of the mechanical properties of the aluminum specimen in the T-direction are shown in Appendix table 5-2 and the corresponding statistical parameters are shown in Table 2.

The raw test data of the mechanical properties of the steel specimen in the L- direction is shown in appendix table 5-3 and the corresponding statistical parameters are shown in Table 3. The raw test data of the mechanical properties of the steel specimen in the T-direction are shown in appendix table 5-4 and the corresponding statistical parameters are shown in Table 4.

These test data clearly showed that the mechanical properties of materials had some variations even having the same specimen of the same materials, tested by the same equipment with the same test procedure. After discussion with faculty, students realized that these variances were because these mechanical properties are random variables and should be described by the statistical models such as a normal distribution function [11]. This data was a treasure for the student research assistants and our school, which will be used in our lecturing again and again. After they went through this entire research process, they were not only able to explain why mechanical properties have some variations but also gained hands-on research experience.

Table 1: statistical parameters of the mechanical properties of aluminum sheet-type specimen in "L"-direction

Mechanical properties	Sample size	Mean (μ)	Standard deviation (σ)	Coefficient of variation (CV)
Percent elongation (%)	50	15.6	1.027	0.066
Yield Strength (ksi)	50	40.8	0.869	0.020
Ultimate Strength (ksi)	50	44.4	0.872	0.020
Young's Modulus(ksi)	50	9406.4	688.4	0.073

Table 2: statistical parameters of the mechanical properties of aluminum sheet-type specimen in "T"-direction

Mechanical properties	Sample size	Mean (μ)	Standard deviation (σ)	Coefficient of variation (CV)
Percent elongation (%)	50	15.0	1.032	0.069
Yield Strength (ksi)	50	41.5	0.758	0.018
Ultimate Strength (ksi)	50	44.8	0.733	0.016
Young's Modulus(ksi)	50	10372.6	1109.2	0.107

Table 3: statistical parameters of the mechanical properties of steel sheet-type specimen in "L"-direction

Mechanical properties	Sample size	Mean (μ)	Standard deviation (σ)	Coefficient of variation (CV)
Percent elongation (%)	50	38.4	2.746	0.072
Yield Strength (ksi)	50	33.2	0.908	0.027
Ultimate Strength (ksi)	50	43.5	1.003	0.023
Young's Modulus(ksi)	50	33166.5	7616.5	0.230

Table 4: statistical parameters of the mechanical properties of steel sheet-type specimen in "T"-direction

Mechanical properties	Sample size	Mean (μ)	Standard deviation (σ)	Coefficient of variation (CV)
Percent elongation (%)	50	40.9	1.096	0.027
Yield Strength (ksi)	50	32.1	0.925	0.029
Ultimate Strength (ksi)	50	44.8	1.057	0.024
Young's Modulus(ksi)	50	34638.0	11428.6	0.330

Table 5 shows the mechanical properties obtained on 6061-T6 sheet specimen vs the published values of the same brand materials. Table 6 shows the mechanical properties obtained on the A1008 (Grade30) sheet specimens vs the published values of the same brand materials. Per the data analysis results shown in Table 5 and Table 6, there were some small differences between the mechanical properties of the aluminum 6061-T6 and the A1008 (Grade 30) steel sheet specimen, The differences were not significant. The comparison of the mechanical properties from our testing with the published values shows that the differences were not significant, except the difference of Young's modulus for the A1008 (Grade 30) steel sheet.

Table 5: the mechanical properties of 6061-T6 specimen vs the published the published values of the same brand materials.

Mechanical properties	6061-T6 in L-direction	6061-T6 in T-direction	Published value
Percent elongation (%)	15.6	15.0	12 (Min.)
Yield Strength (ksi)	40.8	41.5	40.0 (Min.)
Ultimate Strength (ksi)	44.4	44.8	45.0 (Min.)
Young's Modulus(ksi)	9406.4	10372.6	10007

Table 6: the mechanical properties of the A1008 (Grade 30) steel specimen vs the published the published values of the same brand materials.

Mechanical properties	A1008 (Grade 30) steel in L-direction	A1008 (Grade 30) steel in T-direction	Published value
Percent elongation (%)	38.4	40.9	24 (Min.)
Yield Strength (ksi)	33.2	32.1	30 (Min.)
Ultimate Strength (ksi)	43.5	44.8	45(Min.)
Young's Modulus(ksi)	33166.5	34638.0	30000

3. Discussions and conclusions

For a teaching institution, funded research projects are typically very small and limited. Any approach to involving undergraduate students in research will be greatly appreciated and beneficial to the undergraduate students. The involvement of undergraduate students in research is very important for engineering education because it can not only significantly enhance student engagement and enrich the student learning experience, but also can be used as a tool to enhance undergraduate engineering education.

The main purpose of this undergraduate research project was to let students conduct research under the supervision of faculty to answer their questions. This paper discussed a trial at a small private teaching institution which actively involved undergraduate students in doing research for answering some common questions they raised during lectures. This is a small part or a fatigue strength research project. During the entire undergraduate research, students consulted faculty when they had questions and did every activity by themselves. Student research assistants said that from the research project, they not only learned and gained valuable hands-on research experience but also had better and more in-depth understandings of some topics that they had studied because they had implemented them in their research. Some students said that they would like to do more research in the future. Through the research, students gained lots of valuable experiences. Some of these experiences were summarized as they:

- gained hands-on research experience and collecting information skills;
- gained team cooperating skills in the research team;
- gained problem-solving and decision-making skills;
- implemented practically what they learned in the classroom for their research activities;
- gained data analysis skills through a large amount of tensile test data;
- had much better understanding of mechanical properties through testing and data analysis
- recognized that the mechanical properties are actually random variables.

We believed that for teaching institutions, some research projects focused on fundamental common questions or topics raised during courses could be used as undergraduate research projects because (1) the project is manageable and will certainly have some reliable and expected good results, (2) funding requirement is typically not very high when the equipment for the research exists in the institute, and (3) the undergraduate students already have necessary skills to run the research and are able to comprehend the research results.

4. References

[1]. Xiaobin Le, Masoud Olia, Ali Moazed and Richard L. Roberts, *"Design a new set of strength labs for the course of Mechanics of Material,"* the 2016 ASEE annual conference, June 26-29, 2016, New Orleans, LA, USA.

[2]. Yeh, C., "*Undergraduate Research Projects For Engineering Technology Students*", the 2003 ASEE Annual Conference, June 22-25, 2003, Nashville, Tennessee, USA.

[3]. Nambisan, S., "*Involving Undergraduate and High School Students In Research: Opportunities, Challenges, And Rewards*", the 2004 ASEE Annual Conference, June 20-23, 2004, Salt Lake City, Utah, USA.

[4]. Ekenseair, A., & Bayer, C., & Phillips, M., "*Impact Of Integration Of Undergraduate Students In An Engineering Research Laboratory: A Case Study*", the 2009 ASEE Annual Conference & Exposition, June 14-17, 2009, Austin, Texas, USA.

[5]. Hsieh, S., "*Research Experiences for Undergraduate Engineering Students*", the 2013 ASEE Annual Conference & Exposition, June 23-26, Atlanta, Georgia, USA.

[6]. Kaul, S., & Ferguson, C. W., & Yanik, P. M., & Yan, Y., "*Importance of Undergraduate Research: Efficacy and Student Perceptions*", the 2016 ASEE Annual Conference & Exposition, June 26-29, New Orleans, Louisiana, USA.
[7]. ATSM E8/E8m-15a, Standard test methods for tension testing of metallic materials,
[8]. R.C. Hibbeler, "*Mechanics of Materials*", 10 Edition, Prentice Hall; 2013
[9]. R. G. Budynas and J. Keith Nisbett, "*Shigley's mechanical engineering design*", tenth edition, McGraw-Hill, 2014
[10]. R. Shanmugam and R. Chattamvelli, "*Statistics for scientists and engineers*", John Wiley & Sons, Inc, 2015
[11]. E.B Haugen, "Probabilistic mechanical design," Wiley, 1980

5. Appendix

Table 5-1: the mechanical properties of the 10-Gague aluminum sheet-type tensile specimen in "L"-directions

Mechanical properties	Test data
Percent elongation (%)	16.6, 17.0, 16.3, 15.6, 15.9, 15.5, 15.8, 15.1, 14.9, 15.9, 13.8, 12.7, 13.4, 14.5, 15.7, 12.9, 15.0, 15.9, 15.9, 14.8, 16.0, 15.8, 16.3, 16.9, 17.5, 15.1, 15.2, 16.1, 16.6, 15.5, 15.3, 14.7, 16.6, 16.3, 15.6, 16.8, 16.0, 16.2, 16.8, 16.6, 16.3, 15.7, 14.3, 16.4, 14.5, 14.6, 15.7, 16.4, 16.8, 14.9
Yield Strength (ksi)	42.1, 43.0, 41.3, 41.0, 41.9, 42.5, 39.3, 39.1, 40.1, 39.4, 40.4, 40.9, 40.9, 40.5, 40.3, 40.9, 41.1, 39.5, 40.1, 40.6, 39.8, 41.1, 40.7, 39.8, 41.5, 41.8, 41.3, 41.2, 41.4, 41.2, 41.3, 40.8, 40.5, 40.7, 40.6, 39.8, 40.7, 40.0, 40.3, 41.2, 40.0, 40.4, 41.3, 41.4, 40.9, 39.2, 40.2, 41.3, 41.1, 40.7
Ultimate Strength (ksi)	46.2, 47.2, 45.4, 45.3, 45.5, 46.0, 43.0, 42.8, 43.8, 43.1, 44.1, 44.6, 44.4, 44.1, 43.9, 44.2, 44.6, 43.2, 43.4, 44.4, 43.4, 44.7, 44.5, 43.6, 45.2, 45.6, 45.1, 44.6, 45.1, 45.0, 44.9, 44.4,44.0, 44.0, 43.8, 43.5, 44.3, 43.7, 43.9, 44.8, 43.7, 44.0, 44.9, 45.1, 44.4, 43.0, 43.9, 45.0, 44.6, 44.3
Young's Modulus (ksi)	9815.0, 9487.7, 9381.2, 10762.9, 9759.1, 10207.5, 9256.4, 8797.8, 9194.3, 8801.9, 9347.4, 10012.2, 8979.0, 9075.0, 9017.6, 10087.8, 10487.9, 9412.9, 8701.5, 10625.5, 9488.7, 9815.0, 9934.0, 9122.9, 9991.1, 10446.6, 9877.0, 10149.3, 9261.0, 9970.3, 10316.2, 10330.6, 9894.5, 9835.5, 9187.3, 9491.5, 9581.4, 8658.1, 7945.3, 8808.1, 9434.7, 8914.6, 9505.7, 8893.8, 8242.2, 7855.3, 8325.3, 8739.8, 8568.7, 8525.4

Table 5-2: the mechanical properties of the 10-Gauge aluminum sheet-type tensile specimen in "T"-directions

Mechanical properties	Test data
Percent elongation (%)	13.6, 15.2, 14.2, 16.0, 14.8, 14.1, 14.4, 14.9, 14.8, 15.0, 14.0, 14.6, 15.0, 14.8, 14.3, 14.5, 13.5, 14.0, 14.9, 14.1, 16.2, 14.8, 13.8, 15.5, 14.9, 13.8, 14.7, 15.3, 15.3, 15.0, 15.2, 16.4, 15.5, 16.2, 15.6, 17.0, 16.6, 15.0, 17.7, 16.9, 14.4, 14.1, 13.2, 12.4, 14.8, 16.2, 15.4, 16.7, 15.3, 14.4

Yield Strength (ksi)	40.9, 41.0, 40.9, 40.9, 40.9, 41.3, 41.1, 41.6, 41.5, 40.9, 41.6, 41.1, 41.0, 40.6, 41.3, 41.4, 40.8, 41.7, 41.2, 41.2, 41.1, 41.3, 41.1, 40.7, 41.5, 41.3, 41.2, 40.9, 40.3, 40.5, 40.5, 41.8, 41.6, 42.4, 41.7, 40.0, 42.4, 40.5, 42.4, 41.8, 41.9, 42.8, 43.0, 43.0, 42.5, 42.5, 42.6, 42.1, 43.3, 42.0
Ultimate Strength (ksi)	44.3, 44.3, 44.3, 44.0, 44.2, 44.4, 44.3, 45.0, 45.0, 44.3, 45.1, 44.5, 44.4, 43.9, 44.5, 44.4, 44.0, 45.0, 44.7, 44.6, 44.4, 44.7, 44.3, 44.0, 44.8, 44.7, 44.2, 44.1, 43.4, 43.8, 43.7, 45.2, 45.0, 45.9, 45.2, 44.9, 45.8, 44.9, 45.8, 45.1, 44.0, 46.3, 46.2, 46.2, 46.1, 45.9, 46.0, 45.5, 45.5, 45.3
Young's Modulus (ksi)	9449.6, 9823.5, 9916.3, 9744.6, 10113.1, 10592.7, 9784.7, 10057.3, 9770.1, 10169.5, 9387.9, 9774.2, 9861.6, 9504.1, 10347.1, 10475.6, 10210.8, 10779.8, 10060.3, 10493.3, 10651.7, 10128.9, 10289.5, 9835.3, 9617.6, 9532.3, 9786.8, 9152.4, 9892.4, 9341.3, 9073.6, 10961.2, 10166.4, 10645.0, 10698.3, 9842.7, 10308.8, 10397.5, 10526.4, 11405.3, 10954.2, 10907.0, 10747.5, 10762.2, 11836.6, 10503.7, 11267.9, 11490.9, 16886.6, 10702.4

Table 5-3: the mechanical properties of the 12-Gague steel sheet-type tensile specimen in "L"-directions

Mechanical properties	Test data
Percent elongation (%)	42.2, 39.4, 39.3, 40.5, 40.1, 41.8, 43.0, 38.8, 41.0, 40.2, 38.7, 37.4, 37.0, 34.5, 33.5, 35.9, 33.5, 35.8, 34.4, 34.9, 35.6, 35.3, 34.7, 34.7, 37.5, 36.7, 35.0, 35.8, 34.1, 32.0, 40.6, 40.7, 40.7, 40.7, 39.5, 40.3, 39.4, 40.1, 40.2, 40.8, 41.3, 39.5, 40.3, 40.5, 39.8, 40.2, 39.8, 40.9, 38.7, 40.8
Yield Strength (ksi)	34.4, 34.2, 34.1, 35.4, 33.9, 34.5, 34.5, 33.8, 34.5, 35.1, 31.8, 32.8, 33.8, 34.2, 33.5, 33.2, 34.2, 31.7, 32.3, 33.3, 32.0, 32.7, 32.9, 32.1, 33.0, 32.9, 33.0, 32.6, 33.7, 33.4, 31.7, 34.3, 32.8, 33.2, 33.7, 33.2, 32.0, 31.8, 33.2, 32.7, 32.7, 32.0, 33.2, 32.9, 33.2, 32.8, 32.7, 33.0, 32.2, 31.8
Ultimate Strength (ksi)	42.3, 42.8, 43.8, 42.5, 44.0, 43.7, 42.6, 43.0, 43.2, 43.3, 43.3, 41.5, 41.8, 41.5, 42.0, 41.7, 43.2, 43.6, 43.1, 43.7, 43.0, 45.0, 43.4, 43.5, 43.4, 43.4, 43.8, 44.8, 44.6, 43.8, 45.7, 45.3, 44.0, 44.2, 44.5, 44.4, 40.9, 44.8, 43.8, 42.9, 42.6,42.7, 43.5, 44.7, 43.8, 44.2, 43.7, 43.9, 44.1, 43.9
Young's Modulus (ksi)	33032.7, 24078.7, 25415.4, 32803.7, 33801.8, 30980.5, 34012.6, 23283.1, 28593.4, 38413.8, 26381.7, 27455.0, 30138.7, 24140.2, 25572.4, 32209.0, 35773.0, 34936.4, 39492.0, 35032.0, 47553.8, 39459.2, 29614.5, 28647.8, 29195.4, 42262.0, 45015.5, 32543.9, 48504.1, 42077.9, 28632.5, 23041.4, 33141.4, 36544.6, 37781.1, 25350.1, 25356.8, 46116.5, 28955.9, 26043.4, 23031.7, 28304.4, 41189.2, 31972.3, 33652.0, 24350.3, 23755.4, 48462.2, 51060.4, 41164.8

Table 5-4: the mechanical properties of the 12-Gague steel sheet-type tensile specimen in "T"-directions

Mechanical properties	Test data
Percent elongation (%)	40.6, 38.7, 41.1, 38.3, 40.4, 40.3, 40.3, 39.8, 40.9, 40.1, 40.3, 41.4, 40.5, 39.2, 40.3, 39.1, 40.4, 40.7, 41.0, 40.0, 41.9, 41.4, 40.9, 39.7, 39.7, 41.0, 41.6, 41.0, 41.5, 40.6, 40.1, 41.1, 40.0, 42.2, 42.4, 42.1, 41.6, 41.6, 42.0, 42.7, 40.6, 41.1, 40.9, 41.7, 42.4, 41.2, 43.5, 41.7, 43.7, 42.1

Yield Strength (ksi)	30.9, 31.2, 32.3, 31.8, 32.5, 32.4, 31.8, 31.4, 31.3, 31.7, 32.0, 29.7, 30.3, 30.7, 31.2, 30.3, 32.3, 32.0, 32.3, 31.8, 32.2,33. 2, 32.3, 32.2, 32.0, 32.4, 32.5, 33.7, 33.2, 32.6, 34.0, 33.4, 32.2, 33.2, 32.8, 32.7, 29.6, 33.1, 31.7, 31.7, 31.3, 31.3, 31.6, 33.3, 32.1, 32.5, 32.6, 32.2, 32.8, 32.3
Ultimate Strength (ksi)	46.4, 46.2, 46.2, 45.9, 45.9, 45.8, 48.1, 44.9, 46.0, 47.2, 43.1, 44.9, 45.0, 45.7, 45.3, 45.3, 45.8, 43.1, 43.7, 45.0, 43.6, 45.0, 44.8, 43.5, 44.7, 44.0, 44.9, 44.3, 44.5, 44.9, 44.2, 46.2, 44.2, 44.8, 45.6, 44.8, 43.5, 43.3, 44.8, 44.2, 44.6, 43.3, 44.8, 44.1, 45.3, 44.7, 44.6, 44.5, 43.2, 43.6
Young’s Modulus (ksi)	50192.4, 31267.1, 24826.4, 28753.8, 64935.8, 36968.4, 43600.3, 25486.3, 21009.3, 43845.5, 33339.9, 36207.9, 37591.2, 51450.2, 48428.0, 49147.2, 72708.4, 40368.6, 48224.0, 42090.3, 21089.4, 30348.8, 22606.0, 20887.2, 27453.6, 25619.0, 32513.1, 25599.3, 30361.8, 24858.7, 20884.7, 31720.6, 25118.6, 23771.2, 23997.8, 34552.2, 27265.1, 30173.4, 24864.6, 23306.2, 39620.9, 26174.8, 48954.8, 31604.3, 27292.5, 39833.9, 45622.1, 36311.6, 47287.2, 31766.9