2018 ASEE Annual Conference & Exposition
June 24–27, 2018 Salt Palace Convention Center Salt Lake City, UT
Paper ID #22241

Designing and Building Devices for Industry: A Capstone Design Project Experience

Dr. Morteza Nurcheshmeh P.E., Western Kentucky University

Prior to joining WKU, Morteza Nurcheshmeh worked two years as postdoctoral fellow at the University of Windsor. He possesses five years industrial experience in energy auditing, metal cutting, and power generation fields. His teaching specialties are in engineering mechanics, mechanical vibrations, materials science, design and manufacturing processes. Research areas include metal forming processes, forming limits prediction in sheet metals, and formability testing.

Designing and Building Devices for Industry- A Capstone Design Project Experience

Abstract

Logan Aluminum, an integrated aluminum rolling mill in Russellville, Kentucky partnered with Western Kentucky University engineering students in a project to design a system to test the structural integrity of cores used for holding their product. An outcome of project success would be a functioning test machine able to evaluate core strength and thereby allow a systematic assessment to avoid costly core failures.

The student team worked with company engineers to establish system specifications and success criteria for designing a test machine capable of handling two core sizes, and developed a project management plan that allowed them to propose a final design. In the Fall 2015 semester the design phase was finished with an in-depth description of reasoning for major decisions. Design documentation included detailed model drawings, component specifications sheets, calculations, and vendor information. The proposed design was approved at the end of that semester by the local company and a $20,000 budget was provided to students by the industry sponsor to build the system. During the following Spring 2016 semester students worked on acquiring the components, building the device, programming, and testing. The goals of the project were accomplished by the end of the Spring semester.

The device built was very favorably received by the industry partner and they have used it in the production line to test aluminum cores. This capstone project experience proved that engineering students are able to design and build devices which can be very useful for industry partners. Both the industry and the university benefited from the project. Western Kentucky University's partnership with the local company allowed many students like this team to gain real-world experience through the projects. With most of the senior engineering students entering the workforce in less than a year, the challenges and professional expectations of this project have helped prepare students for what is expected in a professional work environment.

Introduction

The Mechanical Engineering (ME) faculty at Western Kentucky University (WKU) utilize a sequence of professional experiences for students pursuing baccalaureate ME degrees that are consistent with the overall mission of the engineering programs. The mission statement is:

> *…to produce, as its graduates, competent engineering practitioners. An engineering practitioner is one who has a foundation of basic science, mathematics, and engineering knowledge, combined with practical knowledge and experience in applying existing technology to contemporary problems. … Program curricula will be project-based. Students will have sufficient opportunity to engage in project activities to support development of a clear understanding of engineering practice. … Projects that provide opportunity to accomplish design, development, and implementation should be available.*

With this mission, the ME faculty members place considerable emphasis on all graduates possessing professional competence. To achieve this outcome, Western Kentucky University ME students experience a curriculum where they can acquire design tools and skills, as well as competency in mathematical and technical analysis and communication [1-2]. The curriculum is consistent with the Criterion 5 requirements EAC of ABET: "*Students must be prepared for engineering practice through a curriculum culminating in a major design experience based on the knowledge and skills acquired in earlier course work and incorporating appropriate engineering standards and multiple realistic constraints.*" [3]

This project was done for Logan Aluminum which is a local company. Logan Aluminum is a large aluminum rolling facility in Russellville, KY which provides aluminum sheet products for a variety of industries. Logan leads the industry in supplying high-quality aluminum sheet metal at low cost to beverage can plants around the world. To meet this goal, Logan continually works towards providing the highest quality sheet at the lowest cost with a safety culture that strives for zero injuries and minimal environmental impact. A team of WKU Mechanical Engineering students who used the moniker of Team Notorious ENG was assigned to design and build a machine for the purpose of testing aluminum cores. The goal of the project was to design a machine that could quickly and accurately measure the structural integrity of corrugated aluminum cores. Starting with a general project outline and scope from the sponsor, the team researched, created design documents to standardize, and built a machine to measure stiffness of the aluminum cores (alucores).

Project overview

Logan's final product is shipped to their customers on corrugated aluminum cores (Alucore) that are formed into tubes from scrap material that are ultimately recycled by the customer. Logan operates a roll forming machine (Alucore Machine) on site that makes these tubes from scrap material. Logan's customer coils are shipped on two diameter sizes of cores depending on the customer specification (15.93 or 19.93 inch diameter), which are standard mandrel diameters for can making equipment. The aluminum cores are cut to lengths between 10.5 and 61 inch on the roll forming machine and then placed in wire basket containers for storage in lots of 50. When an alucore with a certain size is needed, it is placed on the rewind mandrel of the Finishing Machine to coil up the final product.

Before this project, the only form of testing done on the cores after forming and being cut to length was to have the operator attempt to pull it apart. A potential process problem in Finishing is termed a "collapsed coil" where the inner diameter of the coil either distorts or fails completely flat. One of the potential cause of this issue is the inadequate structural integrity of the aluminum core. Due to occurrences of collapsed coils on multiple machine in the past, the WKU Engineering Department has been commissioned to complete crush testing of the cores to measure structural integrity and to provide the data to Logan for equipment troubleshooting purposes.

For testing of Alucores in realistic conditions, a faculty member of Mechanical Engineering program negotiated the details of the project with the industry partner, a team from Logan

Aluminum, to make sure the system is feasible to be designed and built by a team of senior ME students within one year. The goal of the project was to design and build a testing machine that could quickly and accurately measure the structural integrity of the alucore. The machine needed to be simple enough that a shop floor operator could run it with minimal training and intervention. The industry partner provided $20,000 for ordering required components and building the machine. Besides the funding for the project, the industry sponsor team agreed to provide technical assistance to students during the design and building of the project. The primary support by the sponsor was to review design work done by students and to suggest changes to achieve the project goal.

Logan Aluminum provided preliminary information related to the project including photos and videos of the process, previous test reports from the WKU structural testing, a video of a fully collapsed coil coming off a machine, and various pictures of a collapsed coil. Logan also provided sample cores for inspection and testing.

Project specifications

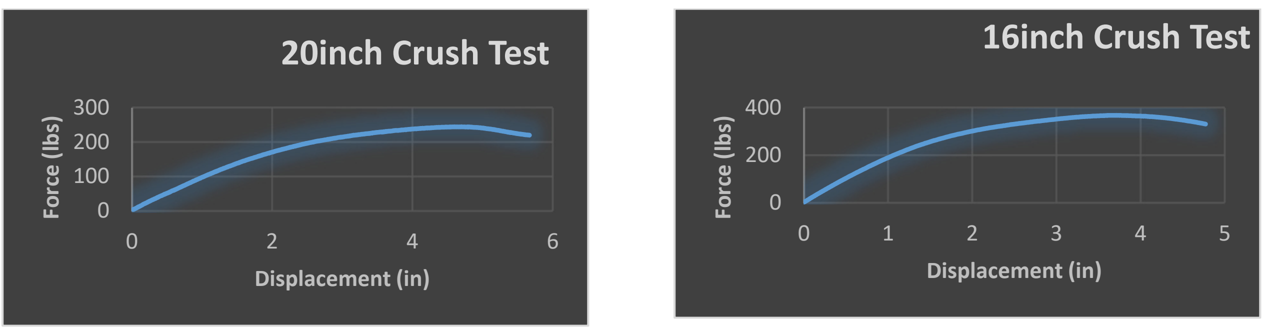
In order to successfully design an alucore testing machine, a team of ME and EE students redefined the problem, made sure that they understand the customer's needs, and determined the project specifications as precisely as possible. The major considerations that students agreed upon with the industry partner were as follows:

1. Alucore tube information
    a. Logan Aluminum produces approximately 150 cores per hour
    b. The test will need to be run once every 50 cores
    c. OD sizes of cores are 15.93 and 19.93 in
    d. The length of the cores varies from 10.5 to 61.00 in
2. General requirements
    a. The machine operation and core testing must be straightforward and simple
    b. Machine testing results must be clear and easily recorded by the operator. The potential exists to have the data automatically transferred to the shop floor computer system, but this is a secondary goal that could be addressed by Logan
    c. The cycle time should be less than two minutes. This test should allow the operator to be away from the existing machine tasks. Therefore, the disruption to the normal operation needs to be minimal. If the cycle time is longer, the student team should provide a detailed breakdown of the time frame needed for the test
    d. The test machine should accommodate the variety of diameters and lengths. If this is not possible and a special length core will need to be cut, then it should be specified
    e. The system should meet Logan machine guarding standards

Test data and graphs

Logan Aluminum provided the Notorious ENG team with samples of both 16 and 20 inch alucores. These samples were cut into sections of 6 inches in length for ease of testing while utilizing WKU's tensile machine. Tests were performed in order to replicate the fundamental principle of the design in this project: that a constant hoop stress increases the amount of force required for failure, thus lowering observational error or measurement error. This is the difference between a measured value of a quantity and its true value. In statistics, an error is not a "mistake", variability is an inherent part of the parameters being measured, and the measurement process causes tolerances, or +/- in measurements. Statistically, the larger the data sampling is, the more precise or the less deviant the data points will be. That does is not mean the data collected will be accurate, but rather consistent [4].

The failure point comparison of cores with and without the straps was very conclusive. Alucores previously were tested in multiple previous studies. In these studies, it was stated that 16-inch alucores withstand a specific maximum force limit. According to the previous reports, during a simple two-point load compression test, the maximum load was 1500 Newton or 337.2 pounds. When a strap was introduced, the maximum force acting on the 16 inch alucore was found to be 1638 Newton or 368.2 pounds. Therefore, a 40 pound or 9.3% increase in vertical load was calculated. The process in which straps were used to simulate a hoop stress is described in the "Design calculations" section of this paper. Figure 1 shows typical test results obtained on both 16 inch and 20 inch cores at WKU.



(a) ***(b)***

Figure 1: (a) Force vs. Displacement curve for 20-inch alucore; (b) Force vs. Displacement curve for 16-inch alucore

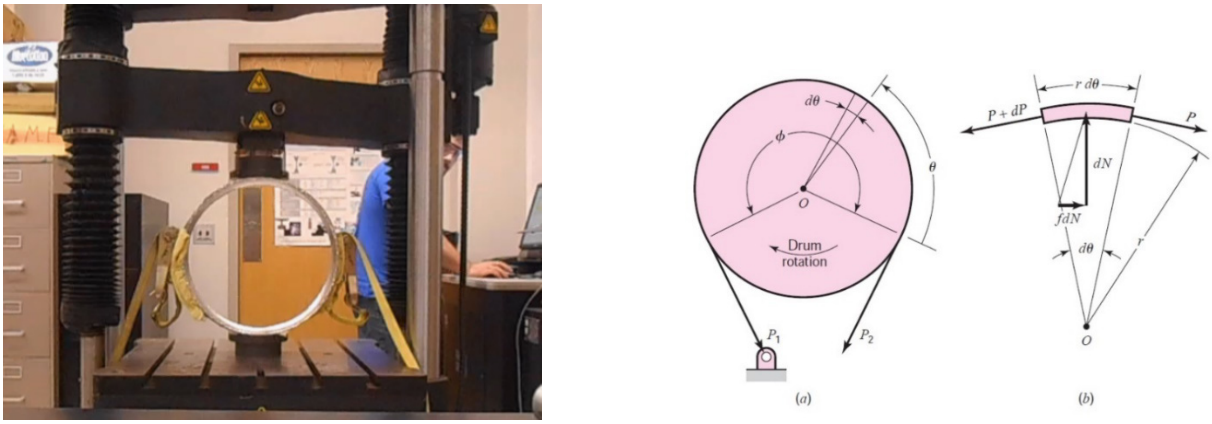
Design calculations

Figure 2 is an image that shows how hoop stress was applied to the outer surface of an alucore using a heavy-duty ratchet strap. These straps were not tightened very much, but merely ratcheted until snug. The purpose of this test was to simulate a supporting hoop stress without creating a stress concentrator at the location of the metal ratchets.

If a stress concentrator had been introduced by any part of the strap, a premature failure could have occurred at the point with the highest stress magnitude. The data collected using this method along with the following equation enabled students to scale the forces that could be seen in the design and to aid in appropriately sizing components such as cylinder size, load cell, strap, and frame with the proper factor of safety [5].

$$\sigma_h = \frac{2(F)}{D(w)} \tag{1}$$

Where σ_h is hoop stress, *F* is the force applied on the core by the strap, *w* is the strap width and *D* is the core diameter.



(a) ***(b)***

Figure 2: (a) Actual testing with straps creating hoop stress; (b) Hoop stresses

Figure 2(b) represents the reaction forces present in the final design for this project. The problem was simulated in the SolidWorks Simulation software. Figure 3 shows the stress result obtained from the analysis based on the predictable forces.

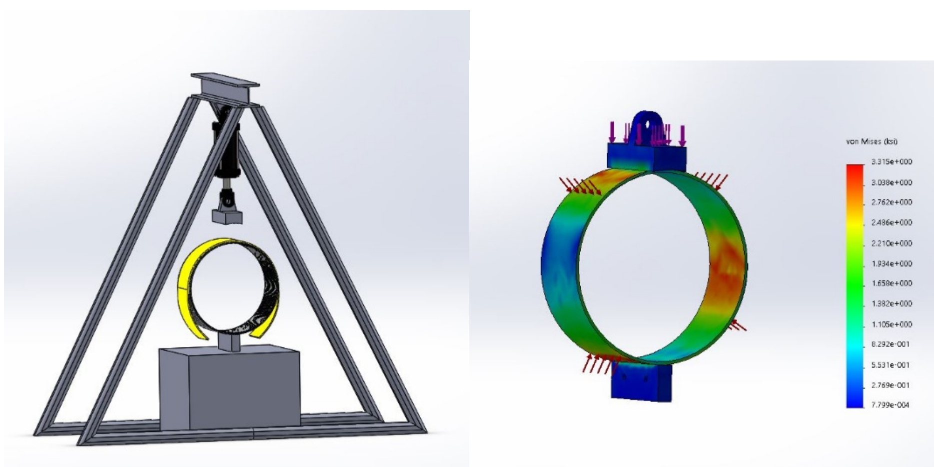


Figure 3: Static loading of hoop stress in the SolidWorks Simulation software

Fabrication considerations

The basic frame was composed of standard I-beam and C-channel. It is a very common material, due to the fact it has high weight to strength ratio, and it can be easily welded or bolted together. This allows for a strong structure and it supports desirable traits necessary for fabrication projects. Ultimately what this means is that the frame design chosen in the project could easily be worked on pieces at a time. Students worked together with industrial contacts to complete the assembly of this machine under supervision and support of the faculty advisor.

The tension in the strap that created the hoop stress in the previous design was done by two cylinders. This was the only way students thought they could achieve the required pushing operation. However, after research and many phone calls with distributors, the students figured out that another solution would be more appropriate. Instead of pushing with two cylinders, they should fix the end of the strap and pull the other end tight, instead of pushing it. This eliminated a cylinder, two check valves, and an electronically controlled 5/3 valve. Additionally, by mounting the cylinder horizontally, the height of the machine was shortened by 13 inches.

Strap selection

Students faced many complications in the beginning as to what type of material could be used for the strap. Initial research found nylon straps were readily available in the size they needed. The test difficulties were: (a) attaching the strap, (b) the 20% stretching property of the nylon, and (c) applying the hoop stress while avoiding strap damage. Seat belts were engineered out of polyester woven into a specific web pattern. This web along with the properties of polyester is highly resistant to stretching. On average, only 2-3% stretch of its initial length makes it perfectly safe and helps to obtain consistent results. Briefly, if yield were to occur and the belt failed, the coil would fall to the ground. In addition, the failure of the nylon results in high energy release that creates a dangerous environment.

Initially, it was a concern that finding these straps could prove difficult, and that even if students found a vendor it would be a custom item potentially very expensive and with extensive lead times. However, many vendors in the northeast of the United States had 12-inch-wide polyester straps. Such straps are the industry standard to lift large boats out of the water at marinas.

Cylinder selection

The size of the machine was an initial concern because factory floor space is very valuable. Therefore, students wanted to be as efficient as possible with the dimensions of the machine in the design phase. Initially, hydraulic pressure was the choice for applying the forces required. After communications with the industry contacts, students found that not only pneumatic cylinders would provide sufficient force, but also they would be cheaper, require less maintenance, and lack the potential to spill hydraulic fluid. To maintain the constant hoop stress throughout the test, the strap tensioning pneumatic cylinder has to remain locked. This was a concern as air is compressible and subject to a “spongy” like a lock. This was corrected by finding a cylinder that is normally locked, but with 15 psi pressure releases the rod to allow motion. When the desired stroke is reached, the air is bled off and the rod is locked and able to endure 650 pounds.

Proposed concept

Multiple initial design concepts were developed by the student team for the alucore crushing machine. The decision on the final design was made during the meetings with industry contacts based on several factors in order to fulfill the requirements of the project. As it is shown in Figure 4 the final design concept developed by the Notorious team used a single pneumatic cylinder on top to tighten the strap to 200 pounds. After the 200 pound force was attained, the rod lock mechanism maintained this tension. The bottom pneumatic cylinder had an adjustable check valve on the exhaust side, allowing for a slow increase of the vertical crushing force. Once the crushing force dropped by 20%, the core failed, and the cylinder returned to the initial position. Once the cylinder was in initial position, the rod lock could be energized, and the strap tension could be released. In case a 20% drop in force never occurred, the program could recognize the end of its stroke, via the Balluf position sensor, and receive a signal to retract. The rest of the design, mainly the purchased components and the construction materials, were chosen based on what was readily available on the market, as well as what components the team felt would best help the overall device meet the specified design criteria.

Figures 4 and 5 show the final product design drawings.

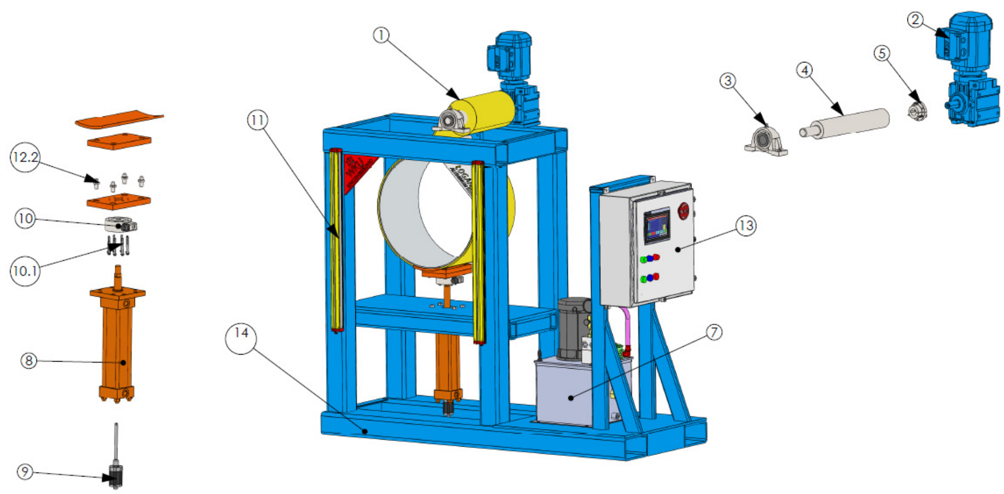


Figure 4: Components of the designed alucore crush tester machine

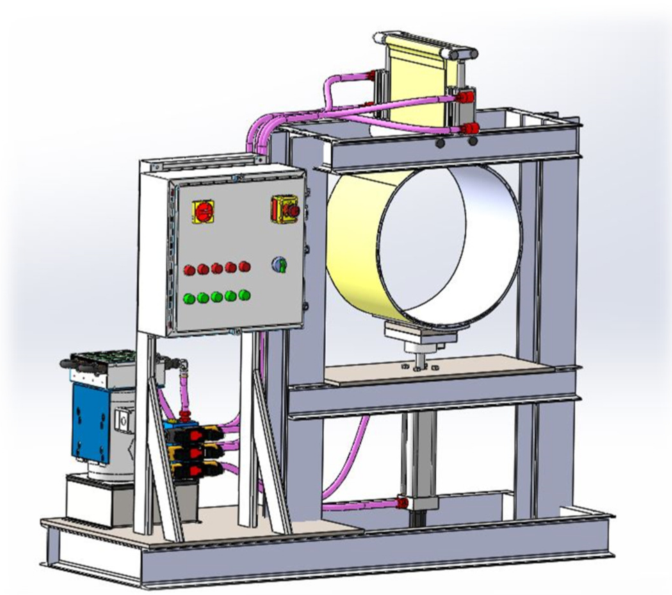


Figure 5: A large polyester strap was used to apply an equal compressive hoop stress around the alucore. The alucore sample could be crushed using a hydraulic ram on the bottom

Table 1 shows the Bill of Material (BOM) and the cost for major components used in building the testing machine

Table 1: Bill of Material (BOM) and cost for major components

Description	**Supplier**	**Cost**
12" Wide Nylon Strap	Atlantic Group Inc.	$200.00
Drive Motor, 1/2HP 230V	Motion Industries	$672.48
Hydraulic Power Unit, 1/2 HP 1Ph 115V, 1GPM	Scott Industries	$2,324.00
Hydraulic Solenoid Valve	Scott Industries	$2,358.60
Directional Spool Valve	McMaster-Carr	$150.00
Hydraulic Ram	Scott Industries	$2,256.92
Balluf Linear Position Sensor	Scott Industries	$220.00
Light Curtain	CED	$1,035.30
NI Data Acquisition Device	Omega	$329.00
Base Mounted Steel Ball Bearing	McMaster-Carr	$111.50
3000 Lbf. Load Cell	Omega	$765.00
All Steel and Build Labor	H&H	$3,920.00
Compact Logix Controller	CED	$1,047.11
Ethernet Cable	CED	$107.16
Software Configurable Safety Relay	CED	$492.80
Guardmaster Ethernet Plug-in Module	CED	$203.00
24V Dc 2 Channel Analog Voltage Input Module	CED	$218.53
PowerFlex 525 AC Drive	CED	$524.00
PanelView 800	CED	$624.00
Essential Power Supply, 24-28V DC	CED	$177.09
Safety Control Relay	CED	$362.71
E1 Plus Solid-State Overload Relay	CED	$54.32
Circuit Breaker	CED	$62.58
One-Circuit Fuse Block	CED	$99.56
30 x 24 x 10, Concept, Type 4 and 12, Steel Enclosure	CED	$335.19
Total cost		**$18,650.87**

The Notorious ENG team spent the Spring 2016 semester to order components, build the machine, crush test multiple samples, and troubleshoot the machine. Figure 6 shows the alucore crush testing machine built by the team and delivered to the industry sponsor in May 2016.

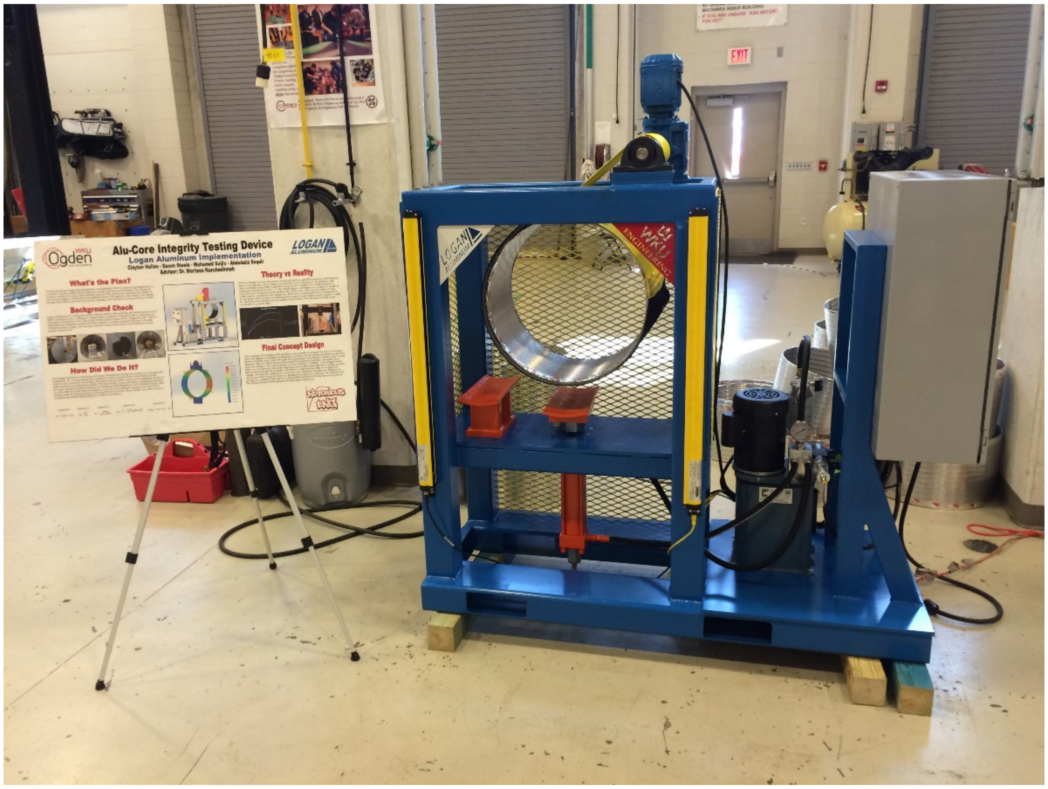


Figure 6: Alucore crush testing machine built by the Notorious ENG team

'Senior Design' course

The course, ME 412, which housed this project is a continuation of ME 400 and provides students with a capstone engineering design experience. The grading in ME 412 is 2/3 team-based and 1/3 individual. The expected course outcomes for ME 412 are: 1) Use structured problem-solving techniques, appraise the needs of clients, produce product/project definition documents, and propose appropriate engineering solutions; 2) Execute a design from inception through completion and convey/document solutions in a wide variety of formats including effective oral business presentations and clear, concise project documentation that flows from general to specific; 3) Successfully manage projects using management tools such as timelines, responsibility charts etc.; and 4) Participate effectively in multi-disciplinary teams, demonstrate that they are effective team members, and evaluate the performance of team members.

Students' performance was assessed via their scores on several intermediate activities related to their final projects (design reviews, update presentations) and the final results of their projects (reports, presentations, and demonstrations). These assignments have been matched with the course outcomes. A target score of 8.0 for all outcomes is based on the need for students to demonstrate competence in these professional components. Students' self-evaluation was consistently either comparable or slightly higher than faculty evaluation; however, students' performance indicates that students have achieved the course outcomes. Peer evaluation which was the weakest area in the past, was improved significantly by using CATME tool as explained in the next paragraph.

As an innovative approach we used CATME Smarter Teamwork system developed in Purdue University for self-evaluation and peer-evaluation which was effective in improving the performance of the student team in running the project. The CATME tool helped our students succeed in their team experiences and develop one of the skills that employers value most: the ability to work effectively in teams.

In general, students are proving themselves to be effective team members, are capable of demonstrating structured problem solving, and are successfully managing projects from inception to completion. Furthermore, the project was an evidence-based practice to demonstrate the design, team-work, and communication skills of our senior ME students in running truly industry-scale projects.

Conclusions

Logan Aluminum came to Western Kentucky University's Engineering Department with the request to create a custom machine for the purpose of testing its alucore material. The goal of the project was to design a machine that could quickly and accurately measure the structural integrity of a corrugated aluminum core. This core is what Logan stores and ships its final product on. As all the acceptance criteria and design specifications were taken into consideration, the design evolved throughout the process to create the best possible product. Initial concepts focused on incorporating hoop stress. It was believed and later tested, that adding a hoop stress would lead to the capability of resisting a greater load than testing without. Some of the initial designs were too complicated or did not properly simulate the forces acting on the alucore during application. This led students to the final design which was accepted and funded by the industry sponsor.

Overall this project provided the experiences necessary to achieve the desired outcomes of our ME Program. In particular, this project was very suitable to the two-course sequence for our capstone senior project, ME400 – Mechanical Engineering Design and ME 412 – Mechanical Engineering Senior Project. The team drafted both the interim and final project status reports to address the specific needs of the sponsor. This project was presented at the 46th WKU Annual Student Research Conference, where their work was favorably reviewed by peers and other faculty within the university community. It was also presented to the Mechanical Engineering Advisory Board.

The Western Kentucky University ME curriculum assures that program graduates have experienced the engineering profession and demonstrated the ability to perform in a professional manner. The team project demonstrated student competence in the areas of Engineering Design, Professional Communications, Professional Tools, and Ethics.

The industry-sponsored design projects in the Senior Design course serve as an effective means to begin the practice of engineering. The project provided an excellent activity for the students to develop and demonstrate their Engineering Design proficiency. It was an appropriate senior-level project because the technical and organizational requirements are adequate for this stage of the educational process. The introduction of a partially defined problem and getting help from an external customer prepares students for expectations after their senior year.

Acknowledgments

The author acknowledges the contributions of the student team: Clayton Hollen, Saxon Steele, Abdulaziz Suqair and Muhamed Suljic. The author would like to acknowledge the support of Logan Aluminum Inc. and Mechanical Engineering Advisory Board members who had generously sponsored this project.

References

[1] K. Schmaltz, C. Byrne, R. Choate and J. Lenoir, "Integrated professional component plan from freshmen experience to senior project", *Proceedings of 2004 ASEE Annual Conference & Exposition,* Salt Lake City, UT, USA, June 20-23, 2004.

[2] C. Byrne, "Student engagement and faculty scholarship", *Proceedings of 2007 ASEE Annual Conference,* Honolulu, Hawaii, USA, June 24-27, 2007.

[3] 2015-2016 Criteria for accrediting engineering programs, Accreditation Board for Engineering and Technology, Baltimore, MD. (http://www.abet.org/wp-content/uploads/2015/05/E001-15-16-EAC-Criteria-03-10-15.pdf)

[4] S. Rabinovich, *Measurement Errors and Uncertainties: Theory and Practice*, 3rd Edition, Springer, 2005.

[5] R. Budynas and K. Nisbett, *Shigley's Mechanical Engineering Design*, 10th Edition, McGraw-Hill Education, 2014.