New Course Development and Assessment Tools in Automotive Lightweighting Technologies

Prof. Raghu Echempati P.E., Kettering University

Professor Echempati is a professor of Mechanical Engineering at Kettering University, (Flint, Mich.). He is a member of ASME, ASEE, and SAE. He has published over 180 technical articles in various peer-reviewed journals and conference publications of repute. He taught at various universities world-wide as a Fulbright scholar, Erskine fellow, or as a visiting professor. He won several academic and technical awards and grants.

New Course Development and Assessment Tools in Automotive Lightweighting Technologies

Abstract

Automotive industry traditionally has reduced weight primarily by downsizing. Today, the strategy of downsizing vehicle has reached its limits. The OEMs are also facing substantial increases in Corporate Average Fuel Economy (CAFE) regulations in the U.S. and the other global markets. In this context, engineering students need to understand the underlying contributors that significantly play a role in vehicle Lightweighting. One of the main contributors is the appropriate use of a variety of high strength and lightweight materials to meet the mass (weight) targets. Another aspect and a more challenging issue is that a realization of how OEMs are learning to cost effectively join (weld, rivet, form and cast) lightweight (and often multi) materials on a global platform. How to impart these ideas in to a single course? The purpose of this paper is to discuss the need and strategic development of undergraduate and graduate level course materials on this topic and the best assessment techniques to gauge the understanding of the topics by the students. The teaching and learning experiences of the author in delivering this course and related topics to two different levels of student audience, and to general technical audience at invited talks and conferences are also briefly discussed in this paper. Finally, at appropriate time, all course material taught will be consolidated for possible publication as an introductory textbook on this subject matter.

KEY WORDS: Automotive Lightweighting, Multi-materials, Joining, Assessment

Background

The need to develop a new course on Automotive Lightweighting comes from the current demands from automotive industries and their suppliers who are interested to employ graduates with basic knowledge in this area learned from a course while they are still in the college. Currently, not many colleges offer a dedicated course on this subject matter, although many topics of this proposed course are addressed in several other core courses such as Manufacturing Technology, Engineering Materials, Mechanics of Materials and Machine Design, Computer Aided Design and Analysis, Automobile Engineering, etc. The Center for Advanced Automotive Technology (CAAT) is one of 42 Advanced Technological Education Centers in the U.S. located at Macomb Community College (MCC, Warren, MI) and Wayne State University (Detroit, MI), who received grant from the National Science Foundation to develop few related courses in automotive materials and lightweighting technologies [1]. MCC in turn approached few other universities and instructors who have some knowledge in this subject area for help in developing few pilot courses and to possibly deliver those to the community college students as series of core courses. Thus, the course developed by the author "Design with Aluminum" under NSF Grant No. 1400593 is one of many other courses that other faculty developed under the major NSF grant.

Although the developed course on lightweighting was primarily targeted to two-year associate degree students of the community college, a slightly modified course on this topic can be offered at the sophomore level, or offered as an elective to senior undergraduate students of a four-year engineering college. Further, with more rigor and content, this course can be offered as an elective to graduate students. This is a work in progress paper as more data is needed to do assessment for continuous improvement of the course delivery and content. It is envisioned that this course when fully developed and delivered to students at the undergraduate and graduate engineering students would enrich the curriculum with a unique and ever growing topic on "Design with Aluminum and other Multi-materials for Automotive Technologies". Just like other courses, this course is meant to provide a development of thinking skills and hands on experience needed for undergraduate engineering students at community colleges, 4-year degree colleges, or for practicing engineers/technicians.

Course learning objectives (CLOs) have been identified (briefly discussed later). The lecture material presented in each module is both developed by the author and from a collection of work available in the literature which is given under References at the end of each module. The pre-requisites for this course are Mechanics of Materials, basic mathematics, computer aided design and engineering, engineering materials and basic manufacturing processes. Industrial experience in the form of internship(s) is also desirable to appreciate the factors affecting the fuel economy.

Literature and proposed topics of coverage

Currently, to the knowledge of the author, there seems to be no single textbook under the title or keywords on "Automotive Lightweighting Technologies" that is targeted for undergraduate and master students. However, material related to some or all topics covered in the proposed course are available in different textbooks, short courses and in many research papers. For example, Case Western University offers certificate program (LIFT Curriculum) that covers topics on lightweighting using polymers, additive manufacturing and metals [2]. University of California, Los Angeles (UCLA) extension offers short courses mainly on aerospace composite materials [3]. Similarly, the Center for Lightweighting Automotive Materials and Processing (CLAMP), at University of Michigan, Dearborn campus offers courses to enhance their graduate education on materials and processes that are used in the production of lightweight automobiles [4]. Their topics cover practical uses of additive manufacturing, advanced materials and polymers as applied to lightweighting challenges. They work collaboratively with industry on research to advance the design, materials technology and testing, and manufacturing processes for life-ling education in producing lightweight automobiles. Likewise, Technical University (TU) Delft offers short course on Design of Lightweight Structures I: Composites & Metals [5]. Historically, aircraft industry has been using aluminum, plastics and composites in order to reduce the weight of its components and the fasteners [6]. Such courses if offered to students in a classroom environment would help them discuss and understand the current trends and applied research in these areas. This would also help them individually and as a group to discuss the pros and cons and the cost benefit analysis of using multi-materials in vehicles.

While most lightweighting materials discussed in the literature talk about plastics and composites as the candidate materials, there are several articles, research papers and industry practices on Lightweighting using aluminum alloys. Examples of this are the all-aluminum Audi A8 and A2 models, as well as the recently redesigned Ford 150 Pickup truck, the majority components of which are made of high strength aluminum alloys [7, 8]. A recent article published by Steel Recycling Institute (SRI) on greenhouse gas and energy studies conclude that the overall environmental impact of vehicle lightweighting using advanced high-strength steel (AHSS) compares better than aluminum [9]. It concludes that vehicles made of advanced high strength steel had lower or equivalent life cycle emissions than aluminum-intensive vehicles for every class of vehicles tested. This list by no means is complete as several professional societies such as ASME, SAE and other agencies offer courses on metals and composites for lightweighting together with joining. These types of contradictory arguments about the use of different types of candidate materials for automobiles require that the students have sufficient knowledge about engineering design, engineering materials and their mechanical as well as structural properties, manufacturing or production techniques, functional performance against corrosion and crash performance, joining issues, etc. Some of the textbooks and other literature which contain topics on this subject matter are given in references [10 to 19].

As mentioned before, it is very challenging to integrate all these topics and aspects in to a single course without the students having some basic knowledge and background in each of these areas. While this may not be a difficult issue for the mechanical engineering students who study many of these topics in the curriculum, what about students from other disciplines who are interested to work in automotive area? This is particularly true these days with several students doing dual degrees and/or minors in other than their parent department. Other areas such as 3D printing technology and additive manufacturing offer development of critical thinking skills among students and faculty to design and manufacture products that are difficult and sometimes impossible by conventional production technologies.

Based on the needs for a new course development in the lightweighting, following topics for the course were identified and these are to be covered at a basic level commensurate with their industrial experience. Real life examples, YouTube videos and other online materials were used to enhance student engagement and discussion from their own experiences from work. As mentioned before lot of literature is available on these topics in various forms. Out of the many, only a sample list of references is presented at the end of each topic as mentioned below.

Topics

Introduction to the course, its importance and challenges in automotive industry (Ref: 2015 North American Light Vehicle Aluminum Content Study - Executive Summary by Ducker Worldwide, June 2014);
Engineering Design: Design methodology, design for assembly and manufacture, design for functional performance, design for optimization, design for sustainability [9, 10].

Material considerations: material selection using Ashby guidelines and charts, comparison between metals and other polymeric materials used in a typical automobile, benefits and best practices [11, 12].
Manufacturing methods and real life automotive products: machining, bulk and sheet forming, casting, forging, rolling and other forming techniques, best practices [13, 14].
Design for functional performance: galvanic corrosion, mixed material design, best practices [15].
Design for cost optimization: cost benefit analysis of steel, aluminum and other polymeric composites in automotive applications, scrap value, recyclability integration of multiple part designs in to a single product, best practices [16].
Characteristics of different grades of aluminum for automotive applications: chemical composition, heat treatment of aluminum, basic types of aluminum extrusions, high volume aluminum alloys, bumpers using advanced aluminum alloys, best practices [17].
Car body structures: types of car body structures, comparison from cost, stiffness and crash performance of different body designs, real life examples [18].

Methodology and course organization

As a first step, it was decided to offer this course to Macomb Community College students who are registered in associate degree program in mechanical engineering [1]. There were 10 students in the class, and they registered for this as a required course under the program they are in. They took this course during their second (and final) year of the program. The course was delivered for 7 weeks, roughly 7.5 hours per week, for a total of around 50 hours. The course lecture duration included class work, exams, and final project presentations. All the ten students were practicing technicians with varied skills in machine operation, or, conducting experiments in a lab, or obtaining field data, etc., but they are not engineers by designation. However, all students are trained in using a CAD tool such as UG-NX [20] that is available to them at the college and at work. Pre-requisite knowledge test in statics, basic math (logarithms, derivatives, exponentials, and trigonometry), manufacturing processes, mechanics of materials, material science and joining processes was given at the beginning of the course to assess their retention of knowledge and to reinstate the importance of understanding of these for the proposed course. Also pre and post course assessment surveys were given to get the feedback from the students of their level of knowledge and understanding on this subject matter.

Since this is a new course, no textbooks are available under this title that contained these topics. Advanced level research papers are available, so do the online materials from company brochures, discussion forums and catalogs. Additionally, some students have personal experience in certain areas of some topics of this course that helped in promoting discussions in the class.

Besides the **course syllabus and a course map**, following learning and assessment tools have been used:

Pre-course assessment survey consisting of 27 questions inquiring about their pre-requisites knowledge of the topics has been conducted (see Appendix A for a list of sample questions)
PowerPoint slide presentations with embedded YouTube videos and other online demonstrations (for example, using Ashby charts)
In-class activities with real life automotive components (both steel and aluminum, for a "Touch and feel" and for comparison)
Class work and Homework (with solutions)
Quizzes (with solutions)
Examinations (with solutions)
Project(s)/Project Presentations
Post-course assessment survey
Others (Field Trips, etc.)

Out of the above, Field trips could not be arranged due to short duration of time to meet and also with conflicts due to class schedule. All students were given access to the lecture material.

Course learning objectives (CLOs)

The following CLOs are identified for this course (will be modified later):

1. Understand the basics of engineering design, design methodology and design process, Design for X (design for manufacture and assembly,
2. Understand the concepts of stress, strain, Hooke's Law; material properties - Young's modulus, stiffness, rigidity, resilience, toughness of engineering materials;
3. Apply knowledge in statics and mechanics of materials in material selection and design;
4. Understand the major metallurgical differences, different types of aluminum alloys (such as 5000, 6000 series), and applications of aluminum;
5. Understand the traditional and non-traditional manufacturing processes (such as Machining, Bulk Forming, Casting, Forging, Foam, Hydroforming, Roll-forming, 3D Printing, etc.) of Aluminum Materials;
6. Develop a basic knowledge of aluminum extrusions and the best practices;
7. Develop an understanding of failure of aluminum due to galvanic corrosion and protection of aluminum joints against such defects;
8. Develop an overall basic knowledge of price of aluminum alloy, weight savings, scrap value;
9. Develop a basic knowledge and confidence of aluminum applications and design guidelines in automobile industry (such as car body structures, etc.);
10. Perform simple research on selection of manufacturing techniques (casting, forging, etc.) of real parts or real life applications using aluminum, and communicate them effectively to the class in the form of presentation;
11. Communicate effectively with aluminum designers, CAE analysts, manufacturing engineers and suppliers at work;

Course delivery and assessment

Course pre-assessment survey has been conducted to understand and to judge their pre-requisites background in the different topic areas of the course. Sample questions assessed based on Likert scale are given in Appendix A. For the in-class activities and problem solving, students were asked to identify the main topic and slide numbers that contain either answer or to search on line if answers are not readily available. The classroom has computer with internet access and so students could find answers to the in-class questions using keywords or phrases on the search engine. Based on their individual effort and group discussions by sharing the variety of answers to the questions, they gained confidence in digging for answers from resources other than the class notes. Since these are commuting students, searching for answers for homework questions and problems made it easier for them. 40% of the grade is assigned for in-class and weekly homework assignments. Two 2-hour exams, including the finals was given with open class notes and lecture material. Exams and pre & post assessment surveys were out of 30% of the final grade while the remaining 30% was assigned for two final projects. The final projects were the effort of two members.

The final project (one sample presented later in this paper) for the course is based on selecting a reasonably complex geometry of an automotive component and develop CAD and production drawings and how some design variations may need to be made if it is made of two different materials. The students were asked to compare steel and aluminum for the project. Each group was expected to work on different automotive component. When possible and if available, grabcad.com [21], an online software was allowed to be used to import geometry or step files directly in to the CAD tool (for example: UG NX or Solid Works) for further design modifications and to compare the physical properties (weight, area, moment of inertia, etc.). Performing FEA was not expected as their knowledge is limited. Although it is known that aluminum parts weigh roughly $1/3^{rd}$ that of steel, they were expected to do design or propose design modifications based on functional design and manufacturability. The overall performance of the students in the class stood at an average course grade of B^+. This being the first time this course was taught for associate degree seeking students, more care and time was spent to help each student succeed in the course.

Scope of the first final project work [22]

The first project was based on aluminum manufacturing processes. The project report is based on the following description:

Research any two aluminum manufacturing processes such as forging, extrusion, rolling, and forming (sheet forming, hydroforming, etc.), and prepare a report in the form of new slides (power point presentation other than the class lecture notes) for submission, as well as, for presentation to the class. Key elements in your presentation should include:

1. Working principle of each process
2. How it works (detailed description)

3.   Type(s) of appropriate material for each process
4.   Pros and cons of each process (cost benefit analysis)
5.   Engineering applications relative to automobiles

Use neat sketches, pictures, and videos based on your own research. Follow the homework format for the slide presentation (Cover slide, objective, process description, specific materials used for the process, applications, references, etc.).

The student performance on this is satisfactory. Some group projects were more descriptive while others contained figures, charts and tabular data.

Scope of the second final project work

The second project was meant to be more CAD intensive as mentioned before. Each group chose different components for the project and carried CAD drawings and studied the physical properties. One of the sample projects was to study the design of rear frame of a Lamborghini vehicle. Image of CAD drawing of this is shown in Figure 1.
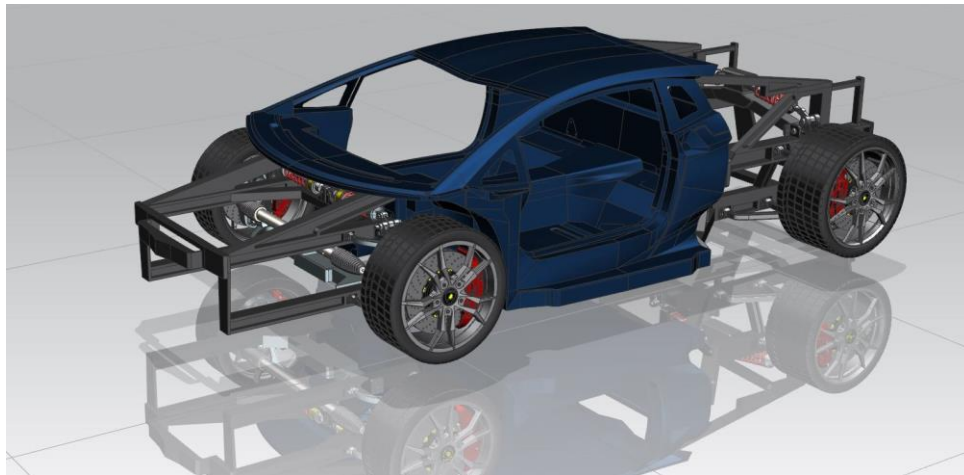

Fig. 1: Rear subframe of a typical automobile (Ref: grabcad.com)

Figure 2 shows the CAD drawing prepared by the group using UG NX CAD tool. Detailed production drawings were prepared for this frame.
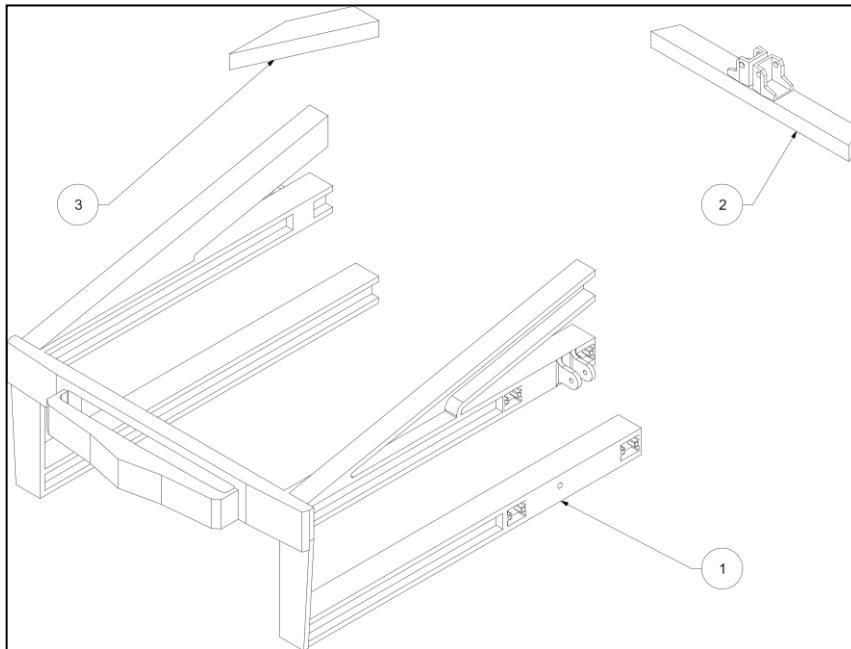
Fig. 2: CAD drawing of the redesigned rear subframe (Ref: group 1 students)

All the components of this frame (1, 2 and 3) were made of steel and are all welded to each other. Figure 3 shows the 3D CAD image of the same subframe using NX.
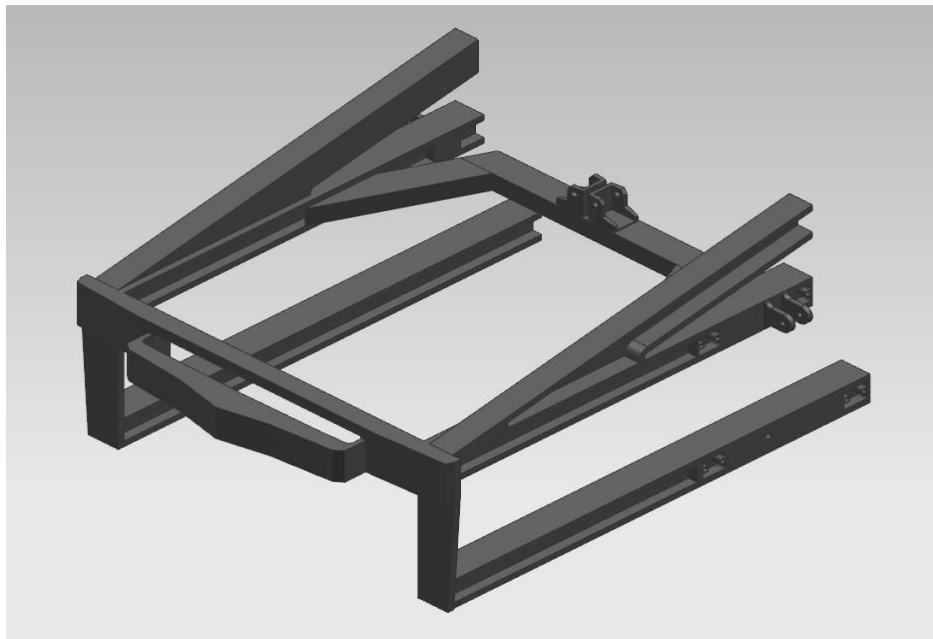

Fig. 3: 3D image of the redesigned rear subframe using NX (Ref: group 1 students)

The physical properties table obtained in NX is shown in Table 1 below.

Table 1: Weight and other physical properties of steel frame

With Steel Applied (Complete Front Frame):

- o   Volume   = 18091924.661079291 mm^3
- o   Area   = 2107596.932153385 mm^2
- o   Mass   = 141.641678172 kg
- o   Weight   = 1389.030363241 N
- o   Radius of Gyration   = 466.323958488 mm
- o   Centroid   = -549.102430121, 1842.820343846, 402.568492788

The students documented the possible manufacturing methods for manufacturing this frame as follows:

Welded Front Subassembly: Front Cross Member and Front Frame Rails
- • All the frame rails and the front cross member can be produced through extrusion.
- • The bumper reinforcement bar can either be extruded, or made of multiple layers of stamped steel.
- • The bosses and through holes can be CNC machined after the extrusion process
- • The front knuckle/ front suspension mounting clevises (pictured above, right), can either be forged and machined/ welded, or if precision is of the utmost importance (which, with it being a Lamborghini - this is most likely the case), then the clevises can be individually CNC machined and then welded onto the frame rails.

Cross-Axis Suspension-Mounting Bar
- • The main rail will most likely be produced by extrusion, with the ends machined off to produce the desired Miter or SAPA joint angle.
- • The horizontally-opposed shock/ strut subassembly mounting clevises (pictured above, right), can either be forged and machined/ welded, or impression die forged and welded (which may still require some CNC machining, but will most likely maintain higher tolerances, therefore needing LESS machining).

Frame-Reinforcement Rails
- • These rails (whose geometry is relatively simple), will definitely be produced by extrusion, with the ends machined off to produce the desired Miter or SAPA joint angle (so as to mate flush with the Cross- Axis Suspensions-Mounting Bar).

Basic material cost estimates to manufacture this steel component was made using online resources such as [23]
https://www.quandl.com/collections/markets/industrial-metals and
http://www.infomine.com/investment/metal-prices/

The current price of steel was based on $300/ton, i.e., around $0.33/kg.

The same exercise was continued by the group in which aluminum rather than steel has been considered. Finally, the pros and cons of using aluminum and steel for the component have been discussed. The final outcome of these projects was that the students gained more knowledge and understood the implications of using aluminum in place of steel, including the challenges in joining steel versus aluminum and the corrosion issues. Crash performance was also discussed. However, due to their limited knowledge, structural and crash analysis using state of the art tools and techniques such as FEA for structural and vibration analysis, and LS-DYNA or other tools for studying the large deformation processes such as crash performance were outside the boundaries of this course taught at the community college level.

The above concepts, topics and ideas have been carried in more rigor and content while teaching the course as an elective to 4-year senior undergraduate and master level engineering students at Kettering University, Flint, MI [24]. They were expected at a minimum to carry out finite element analysis and dig more in to manufacturing and joining issues of steel versus aluminum materials which calls for new design of the parts. These results will be shared later in another paper or shown at the time of the conference.

Assessment and findings

Being the first time this course was offered by the author, no formal assessment was obtained beyond what was observed based on the data from the ten students and those who took this course as an elective. Students were generally happy and did well on the assigned homework, classroom discussions, exams and term-end projects. Examining and assessing their computational skills was done thru their end of the term project reports and presentations. Pre- and post-assessment of their subject knowledge thru survey was helpful to both students and the instructor. The pre-assessment survey based on the 27 questions (please see Appendix A) indicated that the students' familiarity or knowledge in majority of the topic areas was 10% or less. The post-assessment survey conducted at the end of the course and using the same 27 questions indicated that all 10 students felt that they gained more insight in to the different topic areas and learned more than 90% of the subject knowledge taught to them. Within the time limits for the course, satisfactory performance by the student groups was observed. However, a more detailed data needs to be obtained for critical examination and to do meaningful assessment. Field trips would certainly enhance their understanding of the course material better. The overall student performance in the course was satisfactory.

Conclusions

Based on the previous experiences of teaching the similar course material in different courses, the author has developed a new course on Lightweighting technologies for automotive applications. This needs to be further refined and filled with more rigorous content to meet the 4-year and master level engineering students. Assessment tools used in the course seem to be sufficient to gage the performance of the students taking this course although more data is needed. Integration of the math and CAE tools along with

assignment of several mini-projects seems to be an effective way for better understanding of the course material. Validation of computer models and results by hand calculations is imperative that the students must realize. Use of math and/or CAE tools in the class provided them 'what if' scenarios to study the effect of different design requirements and variables on the problem or on the subsystem considered in each project. Students seem to like the group projects and found open ended problems challenging. Such studies can be extended to other engineering courses for their assessment and for continuous improvement of both the course material and performance by the students taking such classes.

Acknowledgements

References

1. Center for Advanced Automotive Technology (CAAT), Macomb Community College homepage available at: http://autocaat.org/Educators/Seed_Funding/Funded_Programs/
2. Case Western University, Ohio, "Advanced Lightweighting Certification Training – Lightweighting Innovations for Tomorrow (LIFT)," certification course. Available at: https://case.edu/cps/courses/lift-program-overview/lift-courses/
3. UCLA extension course, "Engineering & Technology Short Courses". Available at: http://shortcourses.uclaextension.edu/839-88/
4. University of Michigan-Dearborn, "Center for Lightweighting Automotive Materials and Processing (CLAMP)," certification course. Available at: https://umdearborn.edu/cecs/research/centers/center-lightweighting-automotive-materials-and-processing
5. Delft University of Technology, "Design of Lightweight Structures I: Composites & Metals," certification course. Available at: https://online-learning.tudelft.nl/courses/design-of-lightweight-structures-composites-and-metals/
6. National Research Council, "Application of Lightweighting Technology to Military Aircraft, Vessels, and Vehicles," Committee on Benchmarking the Technology and Application of Lightweighting, National Materials and Manufacturing Board, Division on Engineering and Physical Sciences, published by *The National Academic Press*, Washington, D.C., 2012. Available at: www.nap.edu.
7. Audi World, "Historical Background on Use of Aluminum at Audi," published in 2002. Available at: https://www.audiworld.com/news/02/aluminum/content1.shtml
8. Ford Motor Company, "High-Strength, Military-Grade, Aluminum Alloy". Available at: www.ford.com/trucks/f150
9. Greater power and capability. "Lightweighting with Advanced High-Strength Steel Produces Lower Greenhouse Gas Emissions than Lightweighting with Aluminum," *Steel Recycling Institute (SRI)*, February 2018. Available at: http://www.steelsustainability.org/automotive/auto-ghg/?utm_campaign=1068238459&utm_source=google&utm_medium=cpc&utm_content=253129317327&utm_term=%2Blightweighting&adgroupid=52202147437&gclid=EAIaIQobChMI4539r4Xd2QIVGLXACh3TxQ-NEAAYASAAEgLqXvD_BwE

10. K. T. Ulrich and S. D. Eppinger, *Product Design and Development.* McGraw-Hill, 6th edition, 2015.
11. "*NASA's BEST – The Engineering Design Process,*" video series, 2014.
12. M. F. Ashby, *Materials Selection in Mechanical Design.* 5th Edition, 2018, Elsevier, UK.
13. D. R. Askeland and P. P. Phulé *The Science and Engineering of Materials*. Chapter 6, Brooks/Cole publisher, 2003.
14. S. Kalpakjian and S. Schmid, *Manufacturing Engineering & Technology.* 7th edition, Pearson, 2013.
15. The Aluminum Association: http://www.aluminum.org
16. P. R. Roberge, *Corrosion Engineering: Principles and Practice*. McGraw-Hill, 2008.
17. Caffrey, et al, "Cost-Effectiveness of a Lightweight Design for 2020-2025: An Assessment of a Light-Duty Pickup Truck", SAE article 2015.
18. http://european-Aluminum.eu/resource-hub/Aluminum-automotive-manual/
19. *Car Body Structures* – AA Manual
20. UG-NX[®] – Siemens: http://www.ugs.com/
21. Grabcad.com
22. Unpublished projects of the students enrolled in MAT2 Associate Degree Program at Macomb Community College, Warren, MI.
23. *Material prices*. Available at: https://www.quandl.com/collections/markets/industrial-metals and http://www.infomine.com/investment/metal-prices/
24. Elective course offered to senior undergrads and graduate students at Kettering University.

Appendix A

Pre and Post Course Assessment Survey Questions – Design with Aluminum

Please answer the following questions by choosing one of the following numbers (based on Likert scale) against each question:

5-Strongly Agree, 4-Agree, 3-Disagree, 2-Strongly Disagree, 1-N/A

1. I have the knowledge of Different Design Stages.
2. I have the knowledge of Design Methodology and Design Process.
3. I have the knowledge of Design for Functional Performance.
4. I have the knowledge of Design Optimization and Cost Performance.
5. I have the knowledge of Design for Reliability.
6. I have the knowledge of Design for Sustainability and Life Cycle Assessment.
7. I have the knowledge of Benefits and Limitations of Steel versus Aluminum.
8. I have the knowledge of Design with Aluminum along with their Applications.
9. I have the basic knowledge of Statics and Free Body Diagrams.
10. I have the basic knowledge of Mechanics of Materials (or Solid Mechanics).
11. I have a good understanding of material properties of traditional engineering materials (such as steel and aluminum).
12. I have a good understanding of the terms Rigidity and Stiffness of engineering materials.
13. I have a good understanding of the terms Resilience and toughness.
14. I have a good understanding of how Stiffness and Weight Ratio are related.
15. I have a basic understanding of the major Metallurgical Differences and Applications of Aluminum.
16. I have a basic understanding of the traditional Manufacturing Processes (such as Machining, Bulk Forming, Casting, Forging, etc.) of Aluminum Materials.

17. I have a basic understanding of the non-traditional Manufacturing Technologies Aluminum such as Foam, Hydroforming, Roll-forming, Molding and 3D Printing.
18. I have a basic knowledge of Aluminum Extrusions and the Best Practices.
19. I have the basic knowledge of Different types of Aluminum Alloys (such as 2000, 5000, 6000, and 7000 series and their applications as extruded products.
20. I have a basic understanding of Failure of Aluminum due to Galvanic Corrosion and protection of Aluminum Joints against such defects.
21. I have the basic knowledge of Price of Aluminum alloy, Weight savings, Scrap Value.
22. I have basic knowledge of Aluminum Applications in Automobile Industry (such as car body structures, substructures, stamped parts, cast parts, etc.).
23. I have a basic knowledge of the design guidelines for Aluminum Materials.
24. I have the confidence to Design Products using Aluminum Materials.
25. I can Communicate Effectively with Aluminum Designers and CAE Analysts.
26. I can Communicate Effectively with Aluminum Manufacturing Engineers/Suppliers.
27. Overall, I am able to Design and Develop Products with the best choice of Materials.