AC 2012-4677: AN APPROACH TO INCORPORATING SUSTAINABILITY IN A MANUFACTURING ENGINEERING TECHNOLOGY PROGRAM

Dr. Rex C. Kanu, Ball State University

Rex C. Kanu is Coordinator of the Manufacturing Engineering Technology program.

Ms. Pamela Elizabeth Betz, Ball State University

Pamela Elizabeth Betz is a graduate student, having received a master's of arts in adult and community education from Ball State University and currently working toward an Ed.D. in adult, higher, and community education at Ball State. She is currently an instructor of agriculture at Ivy Tech Community College, Marion, Ind.

Dr. Samuel Cotton, Ball State University

Samuel Cotton has been with the Department of Technology for 20 years, specializing in career and technical education. He taught for three and a half years prior to this in secondary career and technical schools in Indiana. In the past decade, he has published 11 refereed articles, and he has presented several times each year at state, national, and international conferences over the past 20 years. He currently serves as the Chair of the Department of Technology at Ball State University in Muncie, Ind.

An Approach to Incorporating Sustainability into a Manufacturing Engineering Technology Program

Abstract

There seems to be a strong perception in many parts of the world that global economic activities are not sustainable given the rate of consumption of non-renewable natural resources such as fossil fuel. For example, since the land-based petroleum findings or wells are being depleted, there is an increasing need to explore the deep seas for petroleum. Similarly, the mining of metal ores is becoming increasingly difficult as many of the easily accessible mines are being depleted. Given this scenario, there is a push from environmentalists, industrialists, and concerned citizens to promote sustainability. However, not everyone agrees on the definition of sustainability. In this paper, sustainability is defined as "the development that meets the needs of the present without compromising the ability of the future generations to meet their own need."[3]

In the Manufacturing Engineering Technology program in a Midwestern University, aspects of sustainability are incorporated into some courses at the freshman, sophomore, and junior levels. The pedagogical tools used to introduce students to sustainability in these courses include presentations, class discussions, homework assignments, and projects. With regard to projects, some students in a junior level plastics course chose to work with a biopolymer, polylactic acid (PLA) and clay nanoparticles to make polymer-clay nanocomposites. PLA is a renewable and environmentally friendly raw material. Clay nanoparticles are naturally occurring materials that are environmentally and ecologically safe. A goal of this project was to introduce the students to the concept of sustainability by researching and working with renewable materials such as PLA and clay nanoparticles in a hands-on laboratory setting. The mechanical and flame retardant properties of the polymer-clay composite were compared with the control, virgin PLA specimens. The results of the project were shared with the entire class via a presentation.

The students' understanding of sustainability was assessed in the course's examination, and the results of the assessment will be shared in a paper presentation at the 2012 conference. It is anticipated that the findings of this paper will be useful to those seeking to introduce their students to sustainability and sustainable development.

Introduction

In *The Prize*, Daniel Yergin[1] claims that the global oil industry began with the first commercial oil well drilled in Titusville, Pennsylvania, USA in 1859, and by 1901 it was claimed that Pennsylvania oil fields produced more than 50 percent of the world's oil supply.[2] Fast forward to 2012, the oil industry in Pennsylvania is for all practical purposes non-existent because its wells have been depleted to levels that are no longer technically and economically viable to extract oil. The wells affected the region economically, socially, and environmentally. The then-booming Pennsylvania oil industry provided employment to its indigenes, attracted skilled labor from other regions and cultures, and increased the value of local properties (cost of farmland, rentals, and home prices); however, it also made some farmlands useless for farming because of soil contaminated caused by oil spillage. One may ask, "What does the history of the oil industry in

Pennsylvania have to do with sustainability?" To answer that question, it is important to define the term "sustainability."

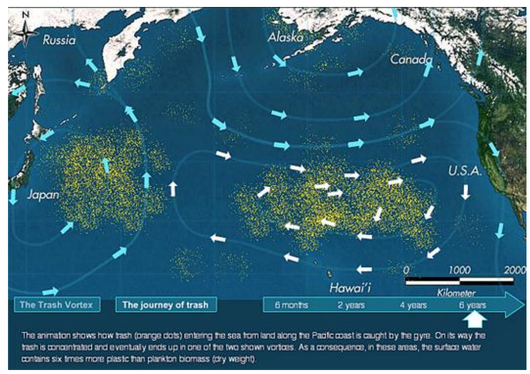
According to the most widely quoted definition of sustainability and sustainable development, which is the definition of the Brundtland Commission of the United Nations on March 20, 1987, "sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs."[3] While this definition applies to all fields of endeavor, Julian Allwood[4] suggests that with regard to manufacturing, sustainability or sustainable development is the ability to "develop technologies to transform materials without emission of greenhouse gases, use of non-renewable or toxic materials or generation of waste." Although Allwood's definition of sustainability is somewhat more restrictive than the Brundtland Commission's definition, it sets an ultimate goal for sustainable manufacturing. It is restrictive in the sense that very few manufacturing processes occur without some form of wastes, no matter how efficient the process may be.

Since the need for sustainability is rather obvious given events like the demise of the Pennsylvania oil industry, how can we promote sustainable practices in our daily activities? Cognizant of this need, Kofi Annan, General-Secretary of the United Nations, in 2001 remarked that "Our biggest challenge in this new century is to take an idea that seems abstract-sustainable development-and turn it into a reality for the entire world's people."[5] The United Nations Decade of Education for Sustainable Development 2005-2014[5] proposed "reorienting educational programs by rethinking and revising education from nursery school through university to include a clear focus on the development of knowledge, skills, perspectives and values related to sustainability that is important to current and future societies" as a means of meeting this challenge. Also, a review of literature indicates that there is a growing body of work proposing the integration of sustainability into higher education.[6,7] In this paper, the authors describe ongoing attempts at Ball State University to incorporate sustainability into its bachelor's degree program in manufacturing engineering technology (MET). Presently, the MET program does not have a course dedicated to teaching sustainability. Hence, the adopted approach is to introduce sustainability as components of some MET courses taught at the freshman, sophomore, and junior levels. These courses include Technical Design Graphics, Manufacturing Materials, and Plastics. None of these components includes Life Cycle Analysis of a product. It is anticipated that life cycle analysis tools such as the Okala Life Cycle Analysis Calculator will be used in assessing sustainability of manufactured products in fall 2012/spring 2013 semesters.

Methodology

In these classes, the impact of human activities on the environment is used to initiate discussions about sustainability and sustainable development. To aid the discussions, slides of Figures 1-4 are shown to the students.

Figure 1. Deforestation in Atlantic Forest Rio de Janeiro - Brazil. This hill was deforested in order to use its clay in civil construction in Barra da Tijuca.[8]



Figures 2a and 2b. According to one sailor, there is an ocean filled with our plastic waste that exceeds the size of the continental United States.[9]

Figures 3a and 3b. The Tilden Open Pit iron ore mine in Michigan, USA. Figure 3a shows the mine in 1930 and Figure 3b shows the mine in its present condition. It has been suggested that the bottom of the mine will soon become the lowest point in the State of Michigan.[10]

Figure 4. Oil spills have fouled drinking water in the Niger Delta. Above: a man in Ogoniland, Nigeria. The Wall Street Journal, August 5, 2011.[11]

Following the discussions on sustainability, students are assigned projects that will integrate particular course content with the concepts of sustainability. Examples of these projects are described in subsequent sections of this paper.

Technical Design Graphics – A Freshman-level Course

The course description states that it is an "introduction to mechanical design and production drawing. Topics covered in the course include sketching, solid modeling, multiview drawings, auxiliary and section views, dimensioning and tolerancing, and the creation of working drawings." As noted earlier, the goal of the project is to integrate skills acquired in the course with the principles of sustainability to develop a new product or modify an existing product. Figure 5 shows a concept pencil sharpener that utilizes used beverage bottles to collect the pencil savings. Figures 6 and 7 show the components of the pencil sharpener while Figure 8 shows an assemble of the components. The designed part was manufactured with a Fused Deposition Machine (FDM) rapid prototyping machine – uPrint™ by Dimension®. The sustainability principle employed in this project is the reduction of material resources by recycling used beverage bottles. This product was designed and built by student Charles Russell.

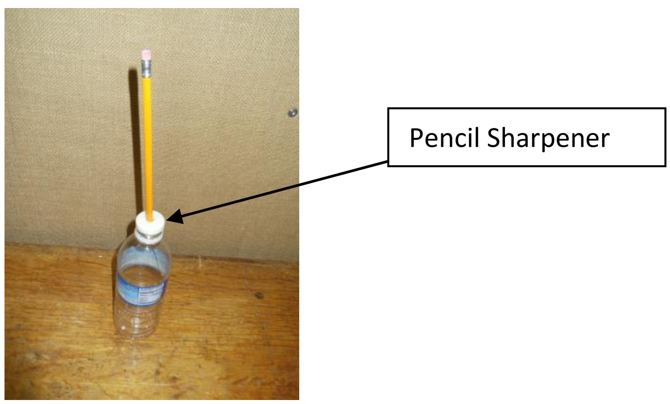


Figure 5. Pencil sharpener and bottle assembly.

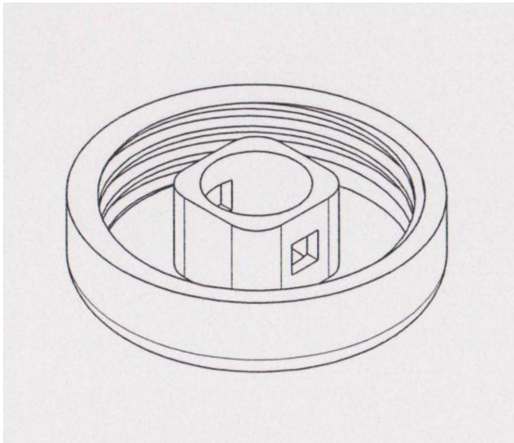


Figure 6. Cap component of assembly

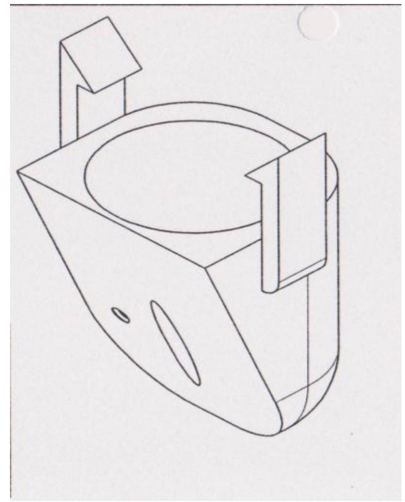


Figure 7. Sharpener component

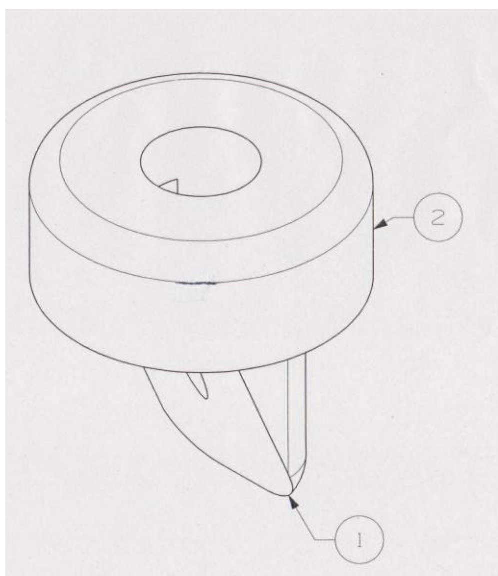


Figure 8. Sharpener assembly consisting of the sharpener (1) and the cap (2)

Manufacturing Materials – A Sophomore-level Course

The course description stresses the "fundamentals of materials science with an emphasis on how material properties influence their application in products and processing. Metallic, polymeric, and ceramic materials will be discussed." A principle of sustainability explored in this course is the impact of materials usage on the environment. Students' projects primarily focused on materials selection using Granta's CES Edupack software that complements the material's textbook by Ashby et. al[14]. CES Edupack has a database for estimating the carbon dioxide (CO_2) footprint of many materials based on their primary and secondary production processes. Thus, the CO_2 footprint of materials can be used as a criterion for selecting appropriate materials for specific applications. Examples of the students projects taken from Ashby et. al[14] are described here. The projects shown here were parts of several projects completed by Karl Rauchenstein.

Project 1. Materials for knife-edges and pivots

Background

Precision instruments like clocks, watches, gyroscopes, and scientific equipment often contain moving parts located by knife-edges or pivots. The accuracy of location is limited by the deformation of the knife-edges or pivot and the mating surface. Choosing materials with high Young's minimizes elastic deformation; plastic deformation is limited by choosing materials with high hardness. Figure 9 shows an example of the use of a knife-edge pivot in a moment weight scale. The strain gauge load cell measures the moment of weight in the hanging pan about the knife-edge pivot.

Requirements:

- *Young's modulus*: as large as possible.
- *Hardness*: as large as possible.
- **Select two or three of the best materials and rank them by their ECO properties.**

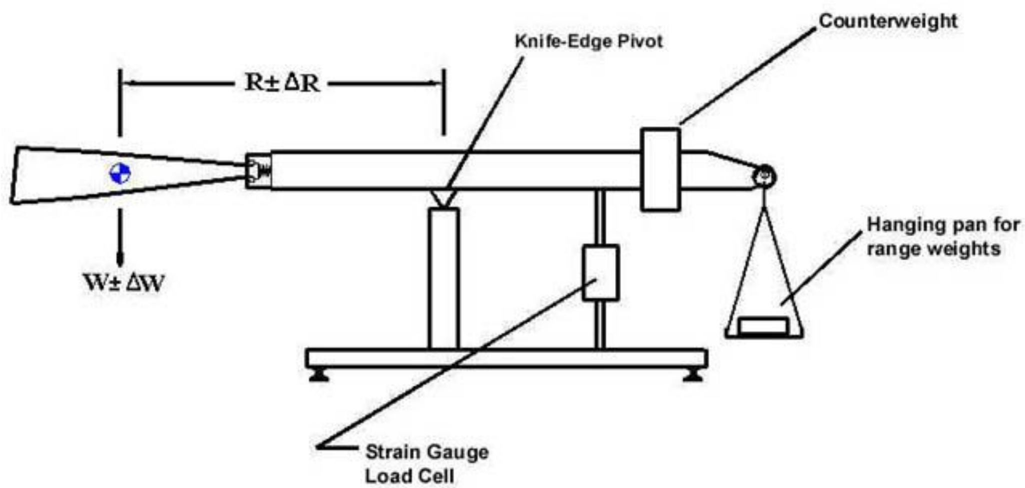


Figure 9. The schematic diagram shows the use of a knife-edge pivot in a moment weight scale.[12]

Results

The ranking of the selected materials was (1) Tungsten Carbide with CO_2 footprint of 4.44lb/lb, (2) Silicon Carbide with CO_2 footprint of 6.25 lb/lb, and (3) Boron Carbide with CO_2 footprint of 8.25 lb/lb. Figure 10 shows the mapping of selected materials in an energy – CO_2 space.

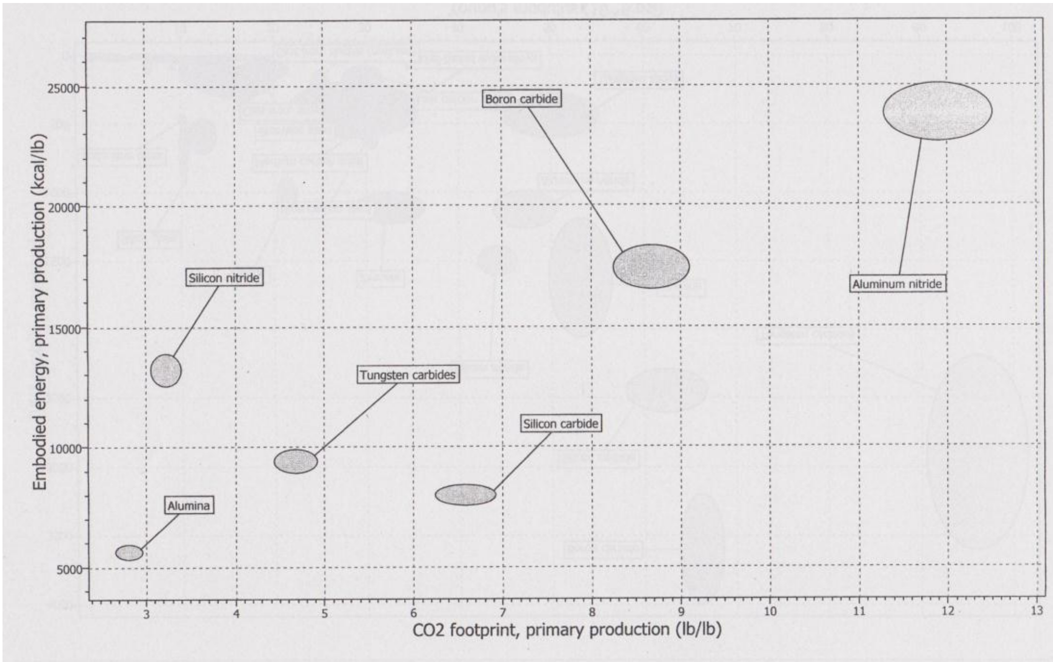


Figure 10. CES Edupack mapping of selected materials for knife-edges and pivots

Project 2**.** Materials for a fresh-water heat exchanger

Background

Heat exchangers typically consist of a set of tubes through which one fluid is pumped, immersed in the chamber through which the other fluid flows; heat passes from one fluid to the other. The material of the tubing must conduct heat well, have a maximum operating temperature above the operating temperature of the device, not corrode in the fluid, and – since the tubes have to be bent – have adequate ductility. Figure 11 shows an example of a U-tube heat exchanger.

Requirements

- Maximum service temperature > 150 °C (423 °K)
- Elongation > 20%
- Corrosion resistance in fresh water: very good
- As large a thermal conductivity as possible.
- Select two or three of the best materials and rank them by their ECO properties.

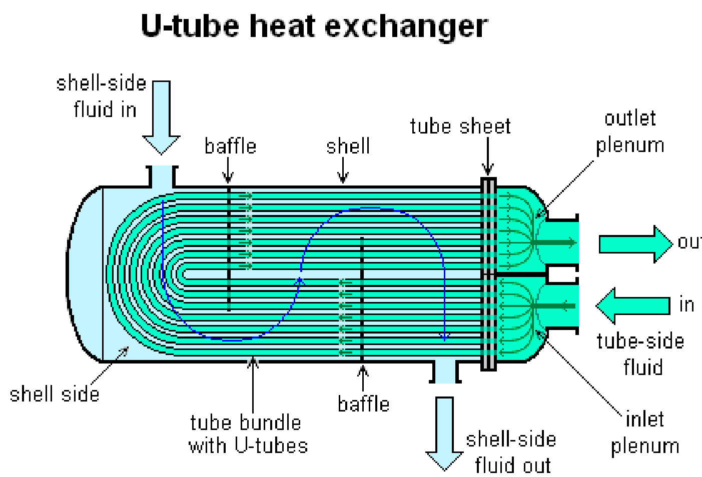


Figure 11. A u-tube heat exchanger[13]

Results

The materials selected were (1) Copper with CO_2 footprint of 4.9 lb/lb, (2) Non Age-hardening Wrought Al-alloys with CO_2 footprint of 11.2 lb/lb, and (3) Brass with CO_2 footprint of 6.5 lb/lb (Brass has lower thermal conductivity than (2)). Figure 12 shows the energy-CO_2 space for ranking materials for the heat exchanger.

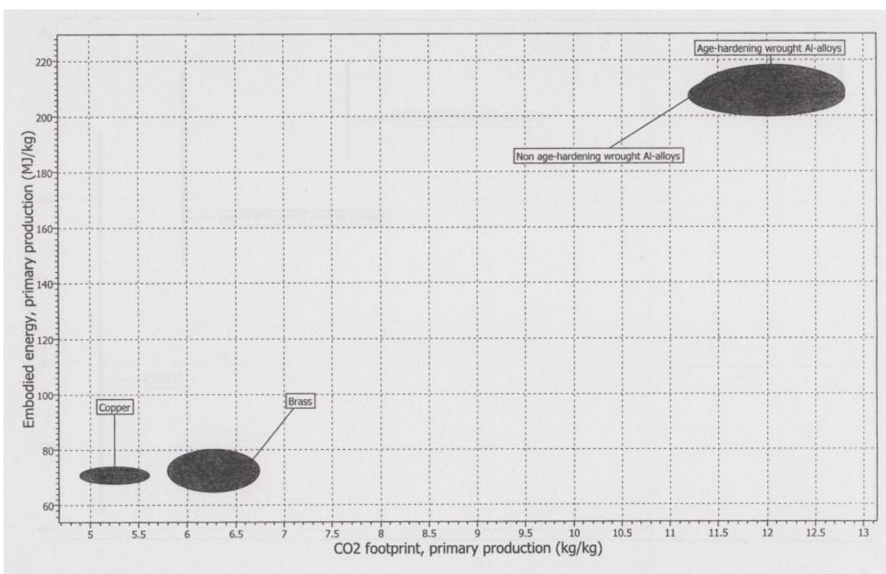


Figure 12. CES Edupack mapping of selected materials for U-Tube heat exchanger

Plastics – A Junior-level Course

The course emphasizes plastics properties and selection, plastics testing based on American Society of Testing and Material (ASTM) standards, and plastics processing. The principle of sustainability that was considered in the course was the use of renewable resources in place of the traditional petroleum-based plastics. Specifically, a project titled "The Effects of Clay Nanoparticles on Polylactic Acid" by Brian Baker, Karl Rauchenstein, and Kyle Ravenscraft examined how incorporating clay nanoparticles into PLA could influence the mechanical properties of the resulting polymer-clay nanocomposite. Polylactic acid (PLA), a biopolymer, is claimed to have similar properties as commercially available polypropylene (PP).

Materials

Plastics: polylactic acid (PLA), Ingeo 3251D™, manufactured by NatureWorks® Clay Nanoparticles: Cloisite® 20A, a natural montmorillonite modified with a quaternary ammonium salt manufactured by Southern Clay Products, Inc.

Equipment

(1) Davis Standard DS-125 extruder was used for melt-compounding PLA and nanoparticles.
(2) A 60-Ton Sandretto Injection Molding Machine was used for preparing ASTM test specimens.

Polymer-clay Nanocomposites

PLA-clay nanocomposites with the following compositions were successfully melt-compounded.

Composition	Weight % of PLA	Weight % of Clay
1	100%	0%
2	99%	1%
3	99.5%	0.5%
4	99.25%	0.75%

Injection Molding of Test Specimens

The injection molding of virgin PLA, composition 1, was done successfully; however, it was difficult to injection mold test specimens with compositions 2, 3, and 4. The nanocomposites became brittle and broke off in the sprue of the mold, which made the molding of sufficient test specimens difficult. Because of this difficulty, the melt-blending step was skipped and a 97/3 weight % mixture of PLA and clay was directly introduced into the injection molding machine and test specimens molded.

The processing conditions used for the injection molding of the test specimens were

Drying temperature	< 110 °F
Drying time	< 6 hours
Rear temperature	300 °F
Middle temperature	330 °F
Front temperature	350 °F
Nozzle temperature	350 °F
Processing (melt) temperature	370 °F
Mold temperature	90 °F
Back pressure	100 psi
Screw speed	75 rpm

Results
There was no significant difference between the modulus of elasticity of the virgin PLA at 159,360 ± 6998 psi and that of PLA/clay nanocomposites at 161,640 ± 4606 psi. The flame test based on ASTM D 3014 showed no significant difference between the control and the PLA-clay nanocomposite specimens as shown in Figure 13. This result suggests that there are exceptions to the general claim that polymer-clay nanocomposites have flame retardant properties. Certainly, this claim was not observed in PLA-clay nanocomposite studied in this work.

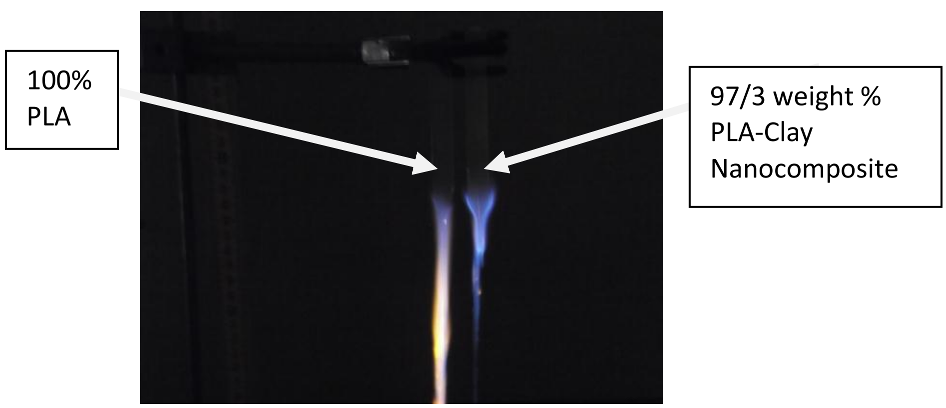


Figure 13. A flame test for neat PLA and 97/3 wt% PLA-Clay Nanocomposite

Assessment

Two instruments, a course examination and a general survey, were used to assess students' knowledge of sustainability. In the plastics course examination the average score on sustainability questions was 80%. The course examination questions were specific to materials covered in class about sustainability and the average score in the examination indicated that the students had a fairly good understanding of materials covered in class on sustainability. In addition to the course examination, a general survey (see Appendix A) was used to assess students' awareness of sustainability beyond materials covered in class. In other words, the survey sort to assess how learning about sustainability was going on beyond materials covered in class. To put the survey in context, the authors will like to inform the readers that this Midwestern University prides itself for being the owner of the largest geothermal project in the US. Thus, it was anticipated that students should be aware of the subject beyond materials covered in class. The results of the survey suggests that more work is required to increase students awareness about sustainability above the current 64% level to at least 80%.

In subsequent years, the authors plan to use the survey differently. That is, they plan to administer the survey in the first week of the semester and during last week of the semester. The results the survey given at different times in a semester will be compared to determine if there were any improvements in students understanding of sustainability in a semester.

Conclusion

MET students were exposed to three aspects of sustainability, namely, recycling, CO_2 footprint (a measure of the impact of human activities on the environment), and the use of renewable resources. Students were introduced to these sustainability concepts through individual and team projects. When examined over the materials covered in class, students scored an average of 80% indicated that they fairly understood the concepts of sustainability. However, when a survey was used to examine if learning was taking place beyond the classroom, the same students scored an average of 64%, which indicated that more work is needed to increase MET students' understanding of sustainability. In this vein, the authors plan to augment the current project approach with product life cycle analysis. This will enable the students to assess the contribution of each stage of product manufacturing to sustainability. Thus, sustainability will be used as a tool to determine the acceptability of a design or a processing technique toward the manufacturing of a product. The Okala Life Cycle Analysis calculator is being explored for this purpose.

It is assumed that the approach adopted at this Midwestern University to promote sustainability and sustainable development among MET students is applicable in most academic institutions, particularly in academic institutions where there are no centralized efforts to incorporate sustainability and sustainable development into their undergraduate programs. This approach will give educators the freedom to be creative in developing teaching methods that best suit their specific environment in teaching sustainability and sustainable development.

Bibliography

1. Yergin, Daniel. "Oil on the Brain: The Beginning." *The Prize*. New York: Simon and Schuster, 2009. 3-18.
2. "The Drake Well in Pennsylvania." *PRIweb.org: Redirecting...* Web. 05 Jan. 2012. <http://www.priweb.org/ed/pgws/history/pennsylvania/pennsylvania2.html>.
3. "DEPweb." *World Bank Group*. Web. 05 Jan. 2012. <http://www.worldbank.org/depweb/english/sd.html>.
4. Allwood, Julian. "What Is Sustainable Manufacturing?" Lecture. Sustainable Manufacturing Seminar Series. UK, Cambridge. 16 Feb. 2005. Jma42@cam.ac.uk.

5. “UN Decade of Education for Sustainable Development 2005-2014.” *UNESCO*. 5 Jan. 2012. <www.unesco.org/education/desd>.
6. Rusinko, Cathy A. “Integrating Sustainability in Higher Education: A Generic Matrix.” *International Journal of Sustainability in Higher Education* 11.3 (2010): 250-59.
7. Mckeown, Rosalyn. “Using Rubrics to Assess Student Knowledge Related to Sustainability.” *Journal of Education for Sustainable Development*. May 2011. Web. 05 Jan. 2012. <http://jsd.sagepub.com/content/5/1/61>.
8. http://en.wikipedia.org/wiki/File:DEFORASTATION_RAIN_FOREST_RIO_DE_JANEIRO_BRAZIL.JPG
9. http://greatpacificgarbagepatch.info/ http://www.californiagreensolutions.com/cgi-bin/gt/tpl.h,content=1690
10. http://www.geo.msu.edu/geogmich/tilden.html
11. http://online.wsj.com/article/SB10001424053111903454504576488113670955644.html
12. http://www.space-electronics.com/Products/MWOperatingConcept.php
13. http://en.wikipedia.org/wiki/Shell_and_tube_heat_exchanger
14. Ashby, Michael, Hugh Shercliff, and David Cabon. “Strategic Thinking: Matching Material to Design.” *Materials: Engineering, Science, Processing and Design*. Amsterdam: Elsevier, 2008. 29-46.

Appendix A

The survey and its results are included here for your review.

1. ____________ is home to the nation’s largest closed geothermal energy system. Geothermal means:

   a. Water cooled.
   b. Energy derived from the heat of the earth.
   c. Energy pulled from the outside air.

   Result: The correct answer is b. Ninety-five percent of the respondents picked this answer correctly, while 5 percent selected c. as their response. No one chose answer a.

2. Much has been discussed about “climate change” in the media. The primary cause of climate change is:

   a. Changes in the solar system.
   b. Historical changes in the atmosphere. The earth is constantly warming.
   c. Global warming brought about by heat-trapping emissions released into the air.

   Result: The correct response is c. with 65 percent of the respondents choosing that answer. Thirty percent chose answer b. and 5 percent did not respond to the question. No one selected a.

3. Plastic bottles and the leeching of toxic chemicals into bottled drinks have been the subject of news articles and recent documentaries. BPAs are one of the main causes of concern. BPAs are:

a. Bisphenol A
b. Bio Aminos
c. Bicloric Acid

Result: The correct response is a. with 65 percent of the respondents choosing this answer. Twenty percent chose c, and 10 percent chose b. Five percent did not respond.

4. Bottled drinking water is a huge industry. The bottled water industry has come under fire recently because

   a. Bottled water is subjected to lower standards than tap water.
   b. Bottled water contributes to large amounts of oil-based plastics being deposited in landfills.
   c. Both a. and b.

   Result: Sixty-five percent of the respondents chose the correct answer c. Twenty-five percent chose b, and 10 percent chose a.

5. Manufacturers are increasingly aware of "sustainable manufacturing." Sustainable manufacturing includes:

   a. Increased manufacturing costs.
   b. The responsible use of resources.
   c. Both a. and b.

   Result: Sixty percent of the respondents chose the correct answer b. Twenty-five percent chose c, and 15 percent did not respond. No one chose a.

6. Many of our plastic products are manufactured from petroleum bases called polymers. There are new sources of polymers called biopolymers. Instead of petroleum, biopolymers are produced from

   a. Living organisms.
   b. Water.
   c. Sand.

   Result: The correct answer is a. and was chosen by 45 percent of the respondents. Thirty-five chose b, and 10 percent chose c. Fifteen percent did not respond.

7. Using biopolymers in the production of plastic products has the following effect:

   a. Biodegradability in landfills
   b. Less reliance on petroleum.

c. Both a. and b.

Result: Answer b is the correct answer with 65 percent of the respondents making this choice. Twenty percent chose a, and none of the respondents chose b. Fifteen percent did not respond

8. Companies that use designs and process in manufacturing that are environmentally friendly experience the following to their bottom line:

a. Higher costs.
b. Lower costs.
c. Higher costs now, that leads to lower costs in the future.
d. All of the above.

Result: Fifty percent of the respondents chose the correct answer which is c. Fifty percent chose a while 5 percent chose b. Fifteen percent did not respond.