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Incorporating Emerging and Sustainable Practices in Teaching Manufacturing Materials

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Incorporating Emerging and Sustainable Practices in Teaching Manufacturing Materials

Abstract

This paper describes the incorporation of emerging and sustainable practices in an undergraduate engineering technology manufacturing materials course. Usually, the laboratory component of a manufacturing materials course includes only industrial testing procedures and experiments. The study of laboratory tests is used to characterize the material properties of ceramic, polymeric, and metallic materials and how these material properties influence material selection decisions in design and manufacturing. This paper discusses the development of lectures and experimental modules for providing undergraduate students learning experience in emerging and sustainable issues in manufacturing materials. The course is intended to incorporate an in-depth overview of emerging sustainable issues in manufacturing and industrial resources to reduce the environmental impact of manufactured products. Green energy manufacturing is an emerging field and also provides a sustainable development model for modern manufacturing industries. Sustainable green manufacturing encompasses the design of manufacturing processes to prioritize energy conservation, pollution prevention or reduction, and increased health and safety of communities, employees, and consumers. In this paper, we will discuss key advanced technologies and environmental topics that can be integrated into manufacturing coursework to include sustainability principles. This course has been taught, evaluated, and reviewed to identify barriers to the inclusion of emerging issues into the course manufacturing materials.

1. Introduction

MET 101 Manufacturing Materials is an undergraduate engineering course taken by freshman level students in the Engineering Technology Department at Drexel University. It is a 4-credit laboratory course held each spring quarter. The students learn the basis of materials engineering, science and technology involves the relationship between the desired properties of a material and the design and manufacturing applications of that material. The students must understand the intimate details of materials in order to design processing and manufacturing techniques that will result in a product with the desired properties. The introduction of manufacturing materials and the broadening applications in aerospace, energy, bio-materials and microelectronics emphasize the need for control of source materials, material components and processing techniques to achieve desired products[1-5].

Current instructional methodology teaches engineering concepts distinctly from sustainability concepts. While courses such as “green manufacturing” and “green/renewable energy manufacturing” exist in ET curricula, students are not taught to look at the environmental impacts of decisions in a traditional engineering course. Additionally, many colleges and universities are not providing all of their graduates with the critical thinking, problem-solving, and sustainable practices required to meet the needs of employers. In order for companies to compete in the global marketplace, employers in the 21st century will require that their engineers couple traditional engineering design skills with newer, modern skills in sustainability, eco design and audit as well as the ability to function in multi-disciplinary teams[6-9]. It is necessary that the students learn and succeed in a multi-disciplinary environment that necessitates a sustainable system approach.

2. Overview of the Course Development

The MET101 Manufacturing Materials course provides the students with a comprehensive knowledge of the characteristic properties of ceramic, polymeric, and metallic materials and how material properties influence the selection of materials for design and manufacturing. The MET101 laboratory includes industrial testing procedures and experiments. The course learning outcomes are: 1. To understand the structure and processing of typical engineering steels, polymers, and ceramic materials, and the circumstances under which they can be used in industry, 2. To conduct tests to measure mechanical properties, making use of data collection and analysis in conjunction with materials selection for design, 3. To predict the microstructures and phases that occur in steels and alloys in general and how microstructure is affected by carbon and alloy contents, and thermo-mechanical heat treatment, and 4. To relate properly their hands-on laboratory experiences to solving real world material and design engineering problems. In order to provide an enhanced hands-on laboratory experience, the students work with real world industrial case studies associated with green energy manufacturing. The below table provides an overview of lecture and laboratory series in MET 101Manufacturing Materials.

Table 1: Overview of lecture and laboratory series

Week	Topic	Labs
1	Introduction to Manufacturing Materials	
2	Mechanical Properties of Materials	Tensile Test
3	Polymeric Materials	
4	Steel Products	Stress & Strain Test
5	Carbon and Alloy Steels	
6	Tool and Stainless Steels	Hardness Test
7	Heat Treatment of Steels	
8	Cast Iron, Cast Steel, and Powder Metallurg Materials	Heat Treatment
9	Engineering Ceramics and Nano-Materials	Piezo-Ceramics test
10	Solar Cell Materials	Solar energy efficiency

The Accreditation Board for Engineering and Technology (ABET) is charged with the task of "Quality assurance in higher education" for programs in applied science, computing, engineering, and technology. Institutions pursuing accreditation must demonstrate that the program meets a set of general criteria[10-11]. Of particular interest are the requirements of Criteria #2, #3, and #5, which are focused on Program Educational Objectives, Program Outcomes and Assessment, and Faculty. These requirements include:

1. A process based on the needs of the program's various constituencies in which the objectives are determined and periodically evaluated (Criterion #2);
2. The students in the program must attain “an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability” (Criterion #3); and
3. The overall competence of the faculty may be judged by such factors as education, diversity of backgrounds, engineering experience, teaching experience, ability to communicate, enthusiasm for developing more effective programs, level of scholarship, participation in professional societies, and licensure as professional engineers (Criterion #5).

Teaching manufacturing materials presents the general challenges of teaching an application rather than a discipline. In that case we could rely heavily on successful practice and then develop principles to explain those successes with selection of materials for design and manufacturing. In the case of sustainable manufacturing materials, other than the real successes of solutions for selecting materials, many of the current ideas (Recycling, Reuse, Remanufacturing, Design for Environment (DfE), Eco-efficiency, etc.) have to offer convincing proof that they actually work[12-14]. Hence, without too much exaggeration, there is neither theory nor much reliable practice to teach. There is also the issue of ethics. Selection decisions with sustainable issues for materials and processes have a dramatic impact on environmental protection, waste management, engineering ethics and social responsibility. Therefore, it is important to incorporate emerging and sustainable practices concepts in the teaching of MET101 Manufacturing Materials. At the end of this course, students have knowledge of sustainable technology and sustainability related to manufacturing materials. The students are able to handle specific problems concerning sustainability and manufacturing materials.

Sustainable Issues with Manufacturing Materials

Students learn the introduction of the sustainable issues to manufacturing materials in the first week. Specially designed assignments and projects have been developed for the course as a part of this practicum, and are necessary to complete many of the exercises in the course. Generally speaking, manufacturing is to convert materials and energy into products. The manufacturing processes provide the job opportunities for people. The products made by manufacturing are to improve our standard of living. To increase the value and quality of the products, supply chain and services have to be involved with the manufacturing processes. One of the outputs must include waste from manufacturing processes. The shadow side of manufacturing needs to be addressed first, such as environmental issues and excess of energy used in industry.

As shown in Figure 1, the fundamental issue in green energy manufacturing is to align manufacturing needs with environmental issues and energy. In addition to the relationship of materials to manufacturing mentioned above, there is a particularly important role for materials selection for environmentally conscious manufacturing. There is an obvious relationship between the properties required in the final product and the properties of the materials that make up the product. However, there often are many materials that will result in the required properties. As engineers and materials scientists, we frequently choose materials with which we are most familiar, and tend to neglect those with which we are less familiar, but which may offer a strong competitive advantage in a variety of ways, from initial material cost, to manufacturability, to the ultimate reuse or recycling of the material and the total life cycle cost and impact.

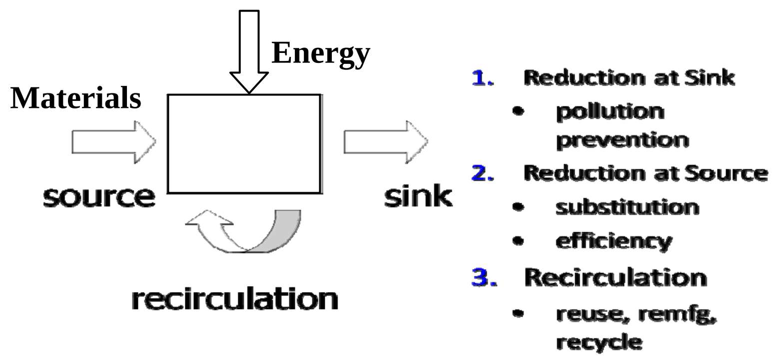


Figure 1: Green Energy Manufacturing

There are two types of manufacturing processes: traditional and non-traditional. The traditional manufacturing itself is perhaps the most important stage in the supply chain in terms of overall environmental impact. Here we shall consider traditional manufacturing materials that apply to metals and plastics, such as: (1) machining, (2) metal casting, (3) metal forming, (4) metal joining, and (5) plastics injection molding. In the past, people were only concerned with the sink or the output in the manufacturing processes with an emphasis on reduction of pollution. Today, the material selection strategies for design and manufacturing are changed due to environmental issues. Recirculation has been added in the new and innovative manufacturing processes, including reuse, remanufacture, and recycle.

Design for the Environment

One important concept covered in MET101 is Design for Environment (DfE). DfE is a philosophy that advocates that consideration be given to the environment when developing new products and processes. DfE is an engineering design initiative that promotes environmentally sound decisions at every step of the production process from chemical design, process engineering, procurement practices, and end product specification to post-use disposal. The concept is developing in the environmental /engineering fields and is beginning to gain public recognition. Therefore, DfE is about industry improving and optimizing the environmental performance of products, impacts on human health, associated risk, product and process costs, efficient use of materials, waste and pollution prevention, and energy conservation.

The industrial ecology view promotes sustainable manufacturing through the modeling of industrial processes after the material and energy flows of the natural environment. An industrial ecosystem follows a cyclic model in which the consumption of energy and materials is optimized, waste generation is minimized, and the byproducts of one process become raw material for another. DfE pursues industrial ecology principles by requiring that industrial designers and managers think in terms of cycles or complex systems rather than traditional linear process flow diagrams. Industry is beginning to consider the environmental impact of a product throughout its life cycle, primarily because of regulatory trends, rising treatment and disposal costs. Corporations are also recognizing the potential economic advantage of DfE. But more training, technical information, and industry-specific knowledge of DfE are needed to bring about its broad-scale implementation. Efforts to develop and integrate DfE with life cycle assessment (LCA) into the production of products and services are under way in the public and private sectors.

Recycling of Plastic Materials

In this course, students also learn the current systems and technology for plastics recycling, life-cycle evidence for the eco-efficiency of plastics recycling, and briefly consider related economic and public interest issues. We focus on production and disposal of packaging as this is the largest single source of waste plastics in the United States and represents an area of considerable recent expansion in recycling initiatives. While plastics have been recycled since the 1970s, the quantities that are recycled vary geographically, according to plastic type and application. Recycling of packaging materials has seen rapid expansion over the last decades in a number of states. Advances in technologies and systems for the collection, sorting and reprocessing of recyclable plastics are creating new opportunities for recycling, and with the combined actions of the public, industry and governments it may be possible to divert the majority of plastic waste from landfills to recycling over the next decades[15-16].

Plastic materials can be recycled in a variety of ways and the ease of recycling varies among polymer type, package design and product type. For example, rigid containers consisting of a single polymer are simpler and more economic to recycle than multi-layer and multi-component packages. Thermoplastics, including PET, PE and PP all have high potential to be mechanically recycled. Thermosetting polymers such as unsaturated polyester or epoxy resin cannot be mechanically recycled, except to be potentially re-used as filler materials once they have been size-reduced or pulverized to fine particles or powders. This is because thermoset plastics are permanently cross-linked in manufacture, and therefore cannot be re-melted and re-formed. Innovative material developments are also introduced to students to inspire their creativity in design. Most plastics are derived from nonrenewable resources, such as oil and gas. But new research shows that plastics can now be made from renewable materials, like starch, plants and farmed crops. Recent breakthroughs mean that conventional plastics-processing equipment can process such materials into a variety of shapes and objects. Importantly, these plastics are also biodegradable.

Metal Recycling

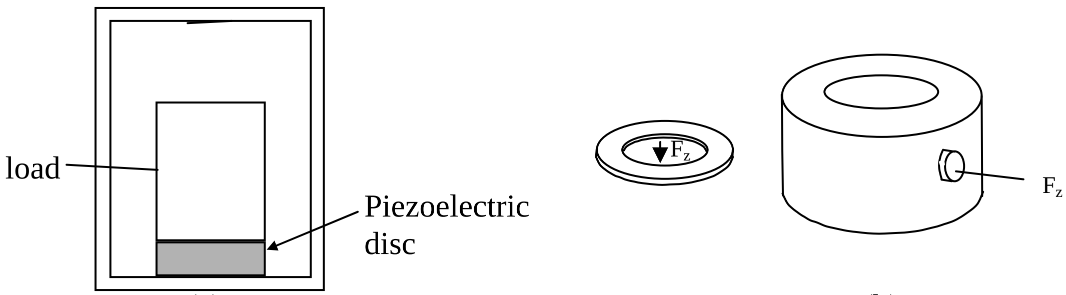
Industry and households constantly produce huge amounts of residual and scrap metals that must be recycled. The recycling of metal starts with the collection of the residual waste metal. The way the collected metal is processed depends on the size, density and purity of the scrap metal. Scrap metal is processed by pressing, crushing, shearing and sorting. Large metal pieces, such as the metal from junk cars, must be made smaller and then separated and cleaned so that the metal can be reused. Scrap metal that is very small in size must be pressed together to prevent the metal from oxidizing and so that it can be reused. The processed scrap metal is melted down into new metal at metal mills[17-19].

Metal recycling involves the processing of recyclable scrap, including the residual raw materials from the manufacturing processes at steel mills and iron foundries, residuals such as sheet metal trimming waste or iron products that have been removed from use. Additionally, the production scrap generated in the metal and engineering industry, i.e. scrap that has not yet been part of an actual end product but is not scrap from the metal manufacturing process, is also recycled. Consumer and construction scrap metal is also processed. Processing recyclable scrap involves size reduction and shearing. Processing production scrap involves size reduction, pressing, shearing and crushing. Methods for processing consumer and construction scrap include size reduction, increasing the density of the mass, cleaning, sorting, shearing, crushing and pressing. Scrap consumption in the United States is maximized between the two types of modern steel mills, each of which generates products that are 100% recyclable and therefore contribute to steel's high recovery rate. One process produces much of the steel for light flat-rolled steel products, with about 30% recycled content. The other process makes steel for a wide range of products, including flat-rolled, but is the only method used domestically for the production of structural shapes, which have over 90% recycled content.

Advanced Technology in Piezoelectric Ceramics

In addition to ceramic materials and applications, students learn about a fascinating electromechanical coupling called piezoelectricity that is being employed and researched around the world for varied purposes – often for creative energy harvesting methods, including generator and motor action. The piezo-electric effect is often encountered in daily life. For example, in small gas grill lighters, a lever applies pressure to a piezo-electric ceramic creating an electric field strong enough to produce a spark to ignite the gas. Furthermore, alarm clocks often use a piezo-electric element. When AC voltage is applied, the piezo-electric material moves at the frequency of the applied voltage and the resulting sound is loud enough to wake even the soundest sleeper. Three main experiments are performed for demonstrating piezo-electric effect on generator and motor actions. Students learn the material properties of a piezo-electric ceramic material and the applications in beam vibration measurement by a piezo-electric accelerometer. They also learn force measurement using a piezo-electric force sensor and the methods involved in operating a piezo-electric actuator for position control at micro/nano scale[20-22].

Students conduct a piezo-electric ceramics material experiment in the ninth week. The purposes of the experiment are for students to understand the mechanical and electrical properties of piezo-electric ceramic material and its applications in generator and motor actions for micro/nano position control. A typical piezoelectric transducer (accelerometer) is shown in Figure 2. In this figure, a small mass is spring loaded against a piezoelectric crystal. When the base vibrates, the load excerted by the mass on the crystal changes with acceleration. The main advantages of the piezoelectric accelerometer include compactness, ruggedness, high sensitivity, and high frequency range.



(a) (b)

Figure 2: (a) Piezoelectric accelerometer and (b) Piezoelectric force sensor

The single-component force sensor provides dynamic and static measurement of the single component of a force (F_z) acting from one direction onto the top plate. This one-component dynamometer contains a quartz ring, where by one is sensitive to compression. The acting force is directly resolved into its single component. The charge voltage yielded by the quartz plate is collected with electrodes connected to the connector of the force sensor. Depending on the direction of the force, positive or negative charges occur at the connection. The second part of this experiment involved using the piezo-electric force sensor. This small part of the experiment involved passing the sensor around, having everyone squeeze the sensor as hard as they can, then seeing the electric output on the oscilloscope.

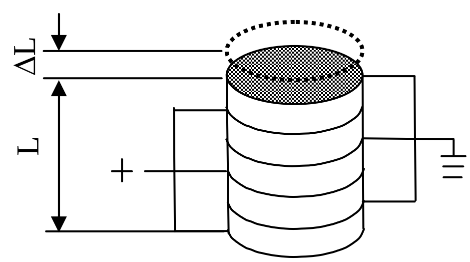


Figure 3: Electrical design of a stack PZT transducer

Piezoelectric actuators are solid state (ceramic) actuators that convert electrical energy directly into motion (mechanical energy) of extremely high resolution. The active part of the positioning element consists of a stack of ceramic disks separated by thin metallic electrodes. The maximum operating voltage is proportional to the thickness of the disks. PZT stack actuators are manufactured with layers from 0.02 to 1 mm thickness. Displacement ΔL of PZT ceramics is primarily a function of the applied electrical field strength , the piezo-electric material used and the length L of the PZT ceramics. Industrial reliability PZT materials can achieve a strain on the order of 1/1000 (0.1%) long PZT actuator can expand by 100 micrometers when the maximum allowable field is applied.

The last part of the experiment is involved with the piezo-electric actuator to measure the deformation of the material when a voltage is applied to it. For this experiment, a voltage was applied to the piezo-electric material and we see how the deformation changes depending on how much voltage is applied to the material.

Applications for Energy Harvesting

Because the Earth's accessible energy resources will not last forever, new technology is needed to ensure that we have ways to generate enough energy in the future. One creative resource is the energy wasted in various forms every day. Examples range from excess heat generated by internal combustion engines to doing work against natural forces, such as friction. Since energy cannot be created or destroyed, only converted into different forms, piezoelectric materials can help us harvest some of this wasted energy for reuse. When we walk, we exert mechanical forces on the ground below us. With every step we take, we lose some energy that is transferred to the ground. Theoretically, this might be used as clothing material to convert our mechanical movements throughout the day into electrical energy, which could in turn be used to power small electronic devices, such as tablets, media players or cell phones. These are just a few of the possible applications for piezo-electrics in the growing field of energy harvesting. Students are encouraged to think critically about other ways in which piezoelectrics could be used to harvest energy from every day mechanical movements, such as walking, climbing stairs, opening and closing doors.

Solar Cell Materials and Energy Efficiency

In the final week of the course, students perform experimental studies of the solar cell materials, and quantify the performance of a photovoltaic cell in terms of efficiency. Thin film photovoltaic cells do come with certain drawbacks, however, among them the difficulty to quantify their mechanical properties and the toxicity of commonly used compounds such as Cd. Students are shown that heat can cause a decrease in a solar panel's power output and that wind can dissipate the heat and return the solar panel to its normal operating condition. Students come to understand that: 1. Wind can dissipate the solar panel's heat and provide for better electrical output, 2. Solar panel efficiency (the ability to convert sunlight into electricity) is negatively affected by heat and improved with cold, and 3. Solar panels operate better in colder weather as compared with warmer weather. Students place a solar panel in direct sunlight or under an artificial light source to allow it to heat up. They record electrical data at selected times in order to determine the rate at which the solar panel loses its ability to generate electricity. Then students cool the solar panel with moving air from a table fan to remove the built-up heat and to witness how the solar panel recovers its power output. Data from cooling are also recorded. Students analyze the data and are given questions to answer the experiments on effect of heat, effect of tilt angle, and effect of shade.

3. Conclusions

This paper describes the incorporation of emerging and sustainable practices for student learning in manufacturing materials. Towards this, weekly lectures and experiments are assigned within the course MET101 Manufacturing Materials so that students complete at the end of each week session. It provides lectures, experiments, demonstrations, and classroom-ready resources appropriate for instruction in the areas of sustainability and manufacturing materials. The course includes traditional materials areas such as metals and ceramics, along with polymeric and plastic materials, with applications in manufacturing, nanotechnology, electronics, and solar cell materials. There were 15-18 students enrolled in the course. Course reviews by students were very positive. Student evaluations were conducted at the last week of the class. According to the results, the course received a 4.3 on 5.0 point ratings, compared with an average rating of 3.4 for the all courses and years at our engineering technology program. Many commented positively about their knowledge gained related to their current jobs in their own companies. Students commented that they enjoyed working in the manufacturing materials laboratory. The results show the highly supportive evidence towards the intended course outcomes.

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