A New Recycling Course Development for Undergraduate Education at WSU

Asmatulu, R., Misak, H. and Khan, W.
Department of Mechanical Engineering, Wichita State University
1845 Fairmount, Wichita, KS 67260-0133

Abstract

The use of recyclable materials has been continuously rising worldwide due to the economic and technological developments. Without recycling these materials, they will get degraded or corroded, and then completely destroyed by the nature, which will be a waste of resources and huge environmental damage. In order to increase the academic and public attentions to recycling, we have developed a three credit hours recycling course "Recycling of Engineering Materials" in the Department of Mechanical Engineering at Wichita State University (WSU), and taught in Spring 2008. The lectures focus on basic characterization and separation techniques of recyclable materials, recycled products, environmental concerns, as well as potential commercial applications. Throughout the lectures, students are expected to gain an understanding of recycling concepts and processing techniques.

1. INTRODUCTION

Recycling is a series of activities consisting of collecting recyclable materials and devices of any kind, which would otherwise be considered waste, sorting and processing into raw materials, such as ferrous and nonferrous metals and alloys, plastics, glasses, ceramics, composites, woods, concretes, asphalts, chemicals and papers [1-3]. There are more than 5,000 recyclable materials available worldwide, and this number continuously increases based on the economical, social and technological developments. Table 1 gives a small portion of recyclable materials, equipments and/or devices that are recycled and reused [1].

Table 1: Some of the recyclable materials, equipments and/or devices that are recycled worldwide.

Automotive Recycling	Plastic Recycling
Ship Recycling	Water Recycling
Battery Recycling	Glass/Fiberglass Recycling
Appliances Recycling	Composite Recycling
PC, Phone and Electronics Recycling	Asphalt Recycling
Non-ferrous Metal Recycling	Tire and Rubber Recycling
Scrap Iron and Steel Recycling	Textile Recycling
Wire and Cable Recycling	Wood Recycling
Precious Metal Recycling	Paint and Adhesive Recycling
Food and Container Recycling	Paper Recycling
Building Materials Recycling	Oil Recycling
Railroad and Bridge Recycling	Chemical and Solvent Recycling
Biomaterials Recycling	New Equipment Recycling
Airplane Recycling	Biological Materials Recycling
Military Materials/Equipments Recycling	Mineral Recycling
Nanomaterials Recycling	Gemstone Recycling

The most of the devices, such as TVs, cellular phones, computers, laptops and music players currently end up in landfills. In addition to valuable metals, such as aluminum, cupper, gold, silver, platinum and stainless steel, these devices often contain hazardous toxic materials (e.g., mercury, lead, cadmium, arsenic, etc.). The toxic materials can contaminate air, soil and water even at smaller quantities and can cause severe environmental and health problems. Table 2 gives some of the toxic materials often used in electric, electronic, communication, printing and copying and computer devices or their manufacturing [1-3,16].

Table 2: Some of the harmful materials and their applications in various fields.

Harmful Materials	**Some of the Applications**
Mercury	Fluorescent lamps that provide backlighting in liquid crystal display (LCDs), in some alkaline batteries and mercury wetted switches
Lead	cathode ray tubes (CRT) screens, batteries, printed wiring boards and paints
Cadmium	Rechargeable NiCd-batteries, fluorescent layer (CRT screens), printer inks and toners and photocopying-machines
Arsenic	Small quantities in the form of gallium arsenide within light emitting diodes
Chromium	Paint industry for corrosion protection and stainless steel
Lithium	Li ion batteries
Barium	Getters in CRTs
Beryllium	Power supply boxes which contain silicon controlled rectifiers and x-ray lenses
Asbestos	Ship manufacturing and other thermal protection area
Americium	Medical equipment, fire detectors and sensing element in smoke detectors
Nickel	Rechargeable NiCd-batteries or NiMH (nickel-metal hydride) batteries, electron gun in CRT and alloying elements
Toner dust	Toner cartridges for laser printers / copiers
Chlorofluorocarbon	Cooling unit and insulation foam
Halogenated compounds*	Condensers, transformers, fire retardants for plastics and flame retardant in printed wiring boards and casings
Trichloroethylene	Its vapor used as a source of chlorine in Si processing, most notably during the thermal oxidation of Si to complex metallic contaminants potentially present on the Si surface

* Polychlorinated biphenyls (PCB), tetrabromo-bisphenol-A (TBBA), polybrominated biphenyls (PBB) and polybrominated diphenyl ethers (PBDE).

Mercury is very dangerous liquid metal since body easily absorbs it via skin contact or inhalation, and can result in serious damage to the central nervous and reproductive systems, as well as irreversible neurological and kidney failures. Like mercury, lead and cadmium are also stored in the fatty tissues, kidneys and/or liver, and have similar side effects on people of every age, animals and other living organisms [1]. Some of the side effects of these hazardous materials remain hidden, and cannot be detected by a clinical examination. In addition to these materials, there are a number of organic substances (e.g., chlorofluorocarbon, halogenated compounds and trichloroethylene) that are heavily utilized by the industry and cause birth defects, miscarriages and other long term mental and physical illnesses [1-3]. In this class, students learn all the health issues of these toxic and hazardous materials and their handelabilities in detail.

2. IMPACTS OF RECYCLING

Recycling saves our environment and future by reducing greenhouse gas emissions, soil contaminations, and air and water pollutions, conserving natural resources and energy, and increasing economic value and job opportunities. There are four main impacts of recycling of materials and devices that students learn in this class [1]:

2.1 Environmental Impact

By reducing the amount of used energy by industry, recycling reduces greenhouse gas emissions and global climate change. Most of the energy used in industrial processes and in transportation is produced by burning fossil fuels, such as gasoline, diesel, coal and other carbon associated sources [1-3]. A new study shows that even 1 degree Celsius increase in temperature by carbon dioxide or other green house gasses (e.g., methane) will cause thousands of deaths and respiratory illnesses in the U.S. [5]. In order to minimize these unwanted emissions and slow global warming, recycling rates need to be increased worldwide. Additional benefits of recycling are to reduce emissions from incinerators and landfills, and slow the harvest of trees.

Soils contaminated by leaching of lead, mercury and other unwanted heavy metals (zinc, tin, cobalt, chromium and cadmium) and their compounds, as well as biologic and nuclear waste materials poses significant health risks to large populations in the world. This is because the contaminated soils will eventually contaminate the agricultural products and other feedstock, and hence poison human and animals in the long term. Current methods used to lower the soil contaminations are too expensive and time consuming for large-scale applications [1,6]. Thus, it is highly recommended to recycle all the materials before sending to landfills and other collection areas. After those unwanted materials interact with the ground, it will take longer time to clean completely.

Recycling can reduce air pollutants, as well [1,6]. Suspended particles in air have a complex mixture of extremely small particles and liquid droplets. The big particles are in the range of 2.5 to 10 μm, whereas the small particles are below 2.5 μm. Particulate pollution consists mainly of a number of components, including acids (nitrates and sulfates), organic chemicals, metals, and soils or dust particles. The largest natural sources of particles are wind-blown dust, volcanoes and forest fires, while the largest human sources of particles are combustion sources, mainly coming from the burning of fossil fuels, internal combustion engines in transportation vehicles, and other coal and natural gas powered stations. Figure 1 shows the sources of particulate matters in the air [1-8].

In addition to greenhouse gas emission and soil and air contaminations, drinking water supplies, such as rivers, lakes and underground water can be contaminated by various sources, which is one of the biggest threats to human being now [1,6]. Instead of obtaining raw materials by mining operations, recycling can eliminate the pollutions associated with material extraction, refining and processing. Mining activities and other manufacturing operations can pollute water resources with toxic materials (e.g., highly acidic and basic solutions, polymers, surfactants, solvents and electrolytes). Also, carbon, sulfur and nitrogen gases can interact with water droplets in air of the atmosphere and return as acid rain (e.g., sulfuric acid, carbonic acid and nitric acid), which directly affect the vegetation, human and animals, as well as increase the corrosion and degradation rates of metals and alloys, polymers, composites and woods [7-9]. This is part of atmospheric corrosion and degradation (Figure 2), which can completely change the properties of materials and destroy them in the long term [9,17].

Figure 1: Sources of particulate matters of forest fire, industrial burning, wind-blow dust and volcano that mainly create air pollutions.

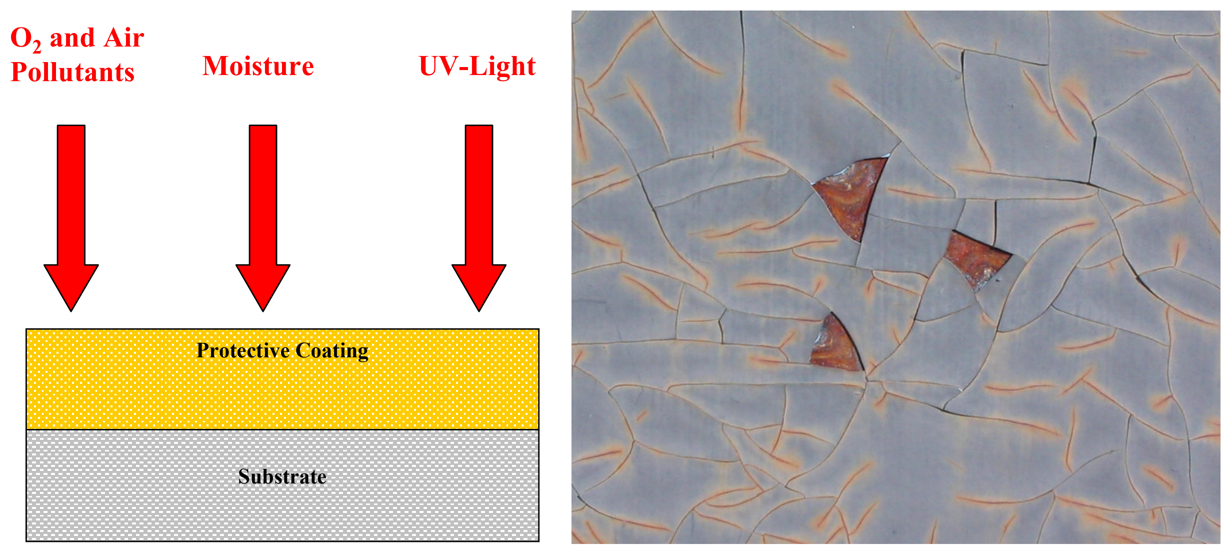

Figure 2: Atmospheric influences on an organic coated metal substrate (left) resulting in degradation and corrosion.

2.2 Economical Impact

Recycling generates significant economic benefits in the region. The recycling of used materials reduces the consumption of raw materials, and other unwanted emission and contaminations as compared to virgin production [1-3]. The creation of secondary raw materials via the recycling route also expends far less energy than a production based on primary raw materials. Table 3 gives the energy savings of various recycled materials [1]. For instance, producing aluminum and copper from scraps means 95% and 85% less energy use, and hence environmental consideration, respectively. Even paper recycling reduces over 60% of the energy during the manufacturing.

Table 3: Energy savings of recycled materials as compared to the virgin productions.

Recycled Materials	Separation Techniques	Energy Savings
Steel	Magnetic, hand sorting	74%
Aluminum	Eddy current, hand sorting, electrostatic	95%
Copper	Eddy current, hand sorting, electrostatic	85%
Lead	Hand sorting, gravity	65%
Paper	Hand sorting, flotation	64%
Plastics	Eddy current, hand sorting, electrostatic	80%

It is estimated that recycling and related remanufacturing industries create over a million jobs and more than $100 billion of revenue in the U.S. [1,10]. Recycling employs all levels of workers from low to high in a wide variety of jobs, including collection, transportation, characterization, separation, processing, new product development and manufacturing, storage and marketing. Many government agencies (e.g., environmental protection agency) in the U.S. provide technical assistance and funds to recycling businesses in all stages. Investments in recycling facilities, equipment and devices contribute to a long term economic growth. Also, using recycled materials and devices will enhance the sustainability and reliability of future products that customers can use without any hesitation or concerns.

2.3 Educational Impact

Like recycling, educational development is of great interest in every major or discipline [18-20]. Recycling education is being offered by many universities as an option or required course in the U.S.A. and around the world. Generally, it involves a multidisciplinary engineering and science education in materials science, chemistry, mechanical, chemical, environmental and electrical engineering. There are also recycling centers and programs in government agencies and private companies that are dedicated to research, development and outreach services for the students, local community and industry by offering courses, seminars, workshops and forums [1-3]. It is believed that research and development in recycling will likely change the traditional design, analysis, and manufacturing methods to produce a wide range of recycled products.

2.4 Social Impact

Recycling activities around the world promote community development and social interactions. The other implications include increased lifespans made possible through a cleaner environment; safer working conditions for employees; increased citizens' interests seeking employment or volunteer work; and improved scientific, cultural and other activities nationally and internationally.

3. WASTE MINIMIZATION

Sources of waste mainly include chemical, mines and quarry, food, nuclear, pharmaceutical, textile and dye-works, petrochemical, pulp and paper mills, iron steel, automobile and agricultural industries, as well as household, schools, hospitals and car-wash stations [1]. Waste minimization is a process and policy of reducing the amount of the toxic hazardous waste. In order to reduce the waste, several strategies have been developed and used worldwide, some of which are listed below [1-4]:

- **Source Reduction:** One of the most desirable methods of waste minimization is to reduce the source used for various purposes, which also reduces the impact of the wastes on the environment and health.
- **Recycling:** Another approach is to reduce the waste through recycling. A waste material is collected, treated and reused in the same or other processes. Recycling promotes the sustainable and long term use of our limited natural resources.
- **Treatment:** The most common method of treatment is to neutralize the waste using chemical, physical and/or biological methods. This will minimize the toxicity of the waste materials.
- **Composting**: Composting is an aerobic decomposition of biodegradable organic matter that can be done both on and off site, which will reduce the amount of mass to landfills and increase the farming production.
- **Donation**: Unspoiled food and clothes can be donated to local food banks, soup kitchens, and shelters. Local and national programs usually offer free pick-up and provide reusable containers. Fats and meat products can be used as raw materials in the rendering industry, which converts them into animal food, cosmetics, soap, and other valuable products.
- **Methane Production:** Food and other organic wastes can be recycled to produce methane gas in a controlled environment for energy production. Uncontrolled methane gas causes climate change and is 21 times more potent than carbon dioxide [1].

4. SEPARATION METHODS

A number of different wet and dry methods have been developed to separate recyclable materials from the general waste stream. Dry methods include hand sorting, dry screening, magnetic, eddy current, electrostatic, optical, air cyclone, pneumatic separations and burning / firing, while wet methods include wet screening, gravity, heavy media, hydrocyclone, centrifugal separations, flotation, and bacterial and acid leaching. Based on the materials properties, size and shape, one or more of these methods are chosen to separate valuable materials [1-3]. When a smaller size separation is needed, waste materials can be crushed, ground and classified in different size fractions, and then sedimentation, filtration, dewatering and/or thermal drying steps take place. Figure 3 shows eddy current and rare earth magnetic separation methods currently employed be the recycling industry [1-6].

5. COURSE CONTENTS

5.1 Course Learning Objectives

The present course, "Recycling of Engineering Materials", is a three credit hour course at 600 level, and meets twice a week for 75 minutes each meeting time during the 14-week semester. This serves as an elective for the students in the Department of Mechanical Engineering and other College of Engineering's senior and graduate level students at WSU. The learning objectives of the proposed course offered in Spring 2008 can be described as follows. After the completion of the course, all the registered students were able to:

- Understand the fundamental principles for the characterization of recyclable materials,
- Apply modern analytical techniques,
- Apply fundamental principles to the separation of recyclable materials,
- Apply computational techniques to the separation methods,
- Understand recycling processes and cost analysis, and
- Demonstrate effective communication and teamwork skills through technical presentations and reports in term projects.

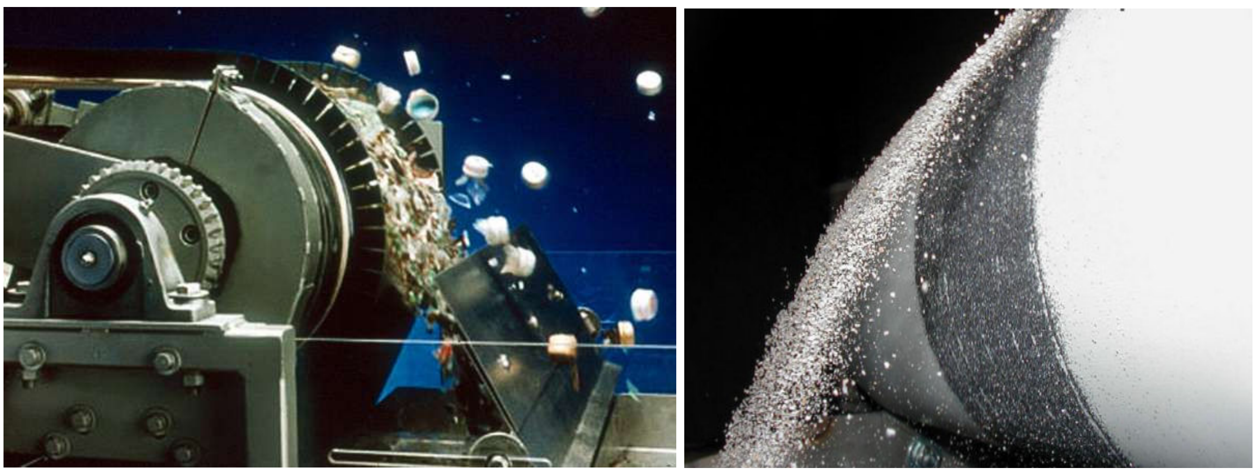

Figure 3: Eddy current separator (left) used to separate plastic, glass, electronics, wood scrap, and automotive shedder residue, while the rare-earth magnetic (right) separator used to separate mostly ferrous metals and alloys.

5.2 Course Textbook

Two books are recommended for the present course, which are given below. In addition to these books, we also prepared and posted our own PowerPoint lecture notes on blackboard using information in the books and other sources.

1. Rao, S.R. "Resource Recovery and Recycling from Metallurgical Wastes,", Elsevier, 2006.
2. Lund, H.F. "Recycling Handbook, 2nd Edition,", McGraw-Hill, 2000.

Various homework assignments and term projects regarding the importance of recycling were given to students to help satisfy their scientific interests in recycling. It is believed that this class broadened the horizons of both undergraduate and graduate students and promoted their interests into research activities of recycling. The prerequisite of this course is Materials Engineering (ME 250). The units of the assessment are given below:

- Homeworks :15%
- Term Project :15%
- Mid-term exam I :20%
- Mid-term exam II :20%
- Final exam :30%

5.3 Course Outline

The present course mainly deals with characterization and separation methods, recycled materials and their environmental and economical effects. Table 4 shows the course outline in detail.

Table 4: The outline of Recycling of Engineering Materials course taught in Spring 2008.

Time Period	**Topics**
Week 1a	Course introduction, Environmental issue
Week 1b	Waste characterization, Size reduction and classification
Week 2a	Optical separation, Gravity separation
Week 2b	Magnetic separation, Electrostatic separation
Week 3a	Chemical leaching, Bacterial leaching,
Week 3b	Flotation (air bubble), Separation by hand sorting
Week 4a	Recycling of paper, Recycling of plastic
Week 4b	Recycling of glass, Recycling of ferrous materials
Week 5a	Recycling of non-ferrous materials, Recycling of cans
Week 5b	Recycling of cables and wires, Recycling of electronics and computers
Week 6a	Recycling of composites, Recycling of constructions
Week 6b	Recycling of oil and chemicals, Recycling of precious materials
Week 7a	Recycling of food (vegetables, animal products, other kitchen products)
Week 7b	Household waste burning
Week 8a	Biological waste disposal
Week 8b	Radioactive waste treatment
Week 9a	Wastewater treatment
Week 9b	Industrial air pollution and its effect
Week 10a	Waste landfill reclamation
Week 10b	Term project presentation
Week 11a	Term project presentation
Week 11b	Term project presentation
Week 12a	Term project presentation

6. COURSE ASSESSMENT SURVEY QUESTIONS

After the course was taught with 35 under graduate and graduate students, a list of survey questions was given to the students to scale from 1 (lowest) to 10 (highest). Following are the questions for quantitative assessment, which are usually asked in the Accreditation Board for Engineering and Technology (ABET) [11-15]. The survey results are given in Table 5. As can be seen from the survey results, most of the students who took the survey scaled between 7 and 10. There is only one student scaled below 5, which confirms that newly developed course in recycling is well understood and established.

1) Please rate your level of understanding of the fundamental concepts in recycling of materials,
2) Please rate your ability to apply the fundamental principles of recycling,
3) Please rate your ability to apply modern analytical techniques to recycling,
4) Please rate your ability to apply computational techniques to recycling,

5) How do you rate your ability to effectively communicate technical information in writing?
6) How do you rate your teamwork skills?
7) How do you rate your ability to make technical presentations?
8) How do you rate your ability to be a self-grower with regard to life long learning?

Table 5: Results of student survey regarding the Recycling of Engineering Materials course.

Questions	**Number of students scaled from 1 to 10**									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
#1	0	0	0	0	0	1	1	5	3	9
#2	0	0	0	0	1	1	1	3	6	6
#3	0	0	0	0	2	1	2	4	4	4
#4	0	0	0	0	3	0	4	2	4	5
#5	0	0	0	1	0	2	4	4	5	6
#6	0	0	0	0	0	0	1	6	5	9
#7	0	0	0	0	0	1	3	4	4	6
#8	0	0	0	0	0	0	2	6	3	7

In addition to the above quantitative course assessment, an SII question was asked, in which the students would list their personal strengths, improvement areas and insights about their background knowledge of recycling. The following SII questions were chosen for an additional post course assessment to facilitate continuous improvement:

1) What are the three strengths of this course?
2) What are the top three things that you have learned?
3) What are the three improvements for this course that would help you learn better?
4) How can these improvements be made?
5) What action plans can be put in place to help you learn more?
6) What have you learned about your own learning process?
7) Is there anything else you would like the instructor to know about the class?

Based on the student background, gender, field of interest, age, employment and nationality, a number of different answers were received from the students. The common answers for the question number 1 are "videos and animations (visual learning), group discussions (active learning) and colorful pictures and drawings (visual learning) describing the subjects", which is also reported in the other studies [11]. The other common answers for the question number 2 are "recycling is very useful class to learn recycling methods for various materials, impact of recycling for environment and future generation, and waste minimization techniques". The SII questions proof that the students pay more attention to the visual and active learning in the class, and gain very useful information about the recycling and its effects.

7. CONCLUSION

Because of the enormous potential of recycling and its impacts, such as environmental, economical and stoical, Recycling of Engineering Materials course has been developed in the Department of Mechanical Engineering at WSU and taught in Spring 2008. It was a three credit hour course and met twice a week for 75 minutes during the 14-week semester. This improved the fundamental and practical knowledge of the students on how to collect, characterize, separate, reprocess and use the recyclable materials economically and efficiently. A course project has also been developed to apply knowledge learned in the course to design a creative recycling process. Students also realized that without recycling the waste materials, they would get corroded or degraded and completely destroyed by the nature, which would be a waste of resources and environmental damages.

REFERENCES

1. Asmatulu, R. "Recycling of Engineering Materials – Class Notes," Wichita State University, 2008.
2. Rao, S.R. "Resource Recovery and Recycling from Metallurgical Wastes,", ELSEVIER, 2006.
3. Lund, H.F. "Recycling Handbook, 2nd Edition,", McGraw-Hill, 2000.
4. www.purdue.edu/rem/hmm/wstmin.htm#Methods%20of%20Waste%20Minimization
5. Jacobson, M.Z. "On the causal link between carbon dioxide and air pollution mortality," *Geophysical Research Letters*, Vol. 35, 2008, L03809.
6. Rubin, H., Narkis, N. and Carberry, J. "Soil and Aquifer Pollution: Non-Aqueous Phase Liquids – Contamination," Springer, 1998.
7. Revie, R.W. and Henry, U.H. "Corrosion and Corrosion Control –An Introduction to Corrosion Science and Engineering, 4th Edition," Wiley-Interscience, 2008.
8. Ahmad, Z. "Principles of Corrosion Engineering and Corrosion Control," IChemE, 2006.
9. Asmatulu, R. "Introduction to Corrosion – Class Notes," Wichita State University, 2008.
10. http://www.epa.gov/jtr/econ/index.htm
11. Anderson, L.W. and Krahwoh, D.R. (Eds.) "A taxonomy for learning, teaching and assesining: a revision of Bloom's Taxonomy of education objectives: complete edition", New York, Longman, 2001.
12. Griffin, R., Karaman, I., Ma, J., Grulan, J. and Froyd, J. "Development of a nano-filled composite experiment for a freshman class," 114th Annual ASEE Conference & Exposition, June 24-27, 2007, Honolulu, HI.
13. Kelkar, A. and Bolick, R. "Nanoengineering of structural materials," 114th Annual ASEE Conference & Exposition, June 24-27, 2007, Honolulu, HI.
14. Dong, Y. and El-Sayed, J. "Mechanics, process, and design simulation of fiber-reinforced composite materials – a new course development," 114th Annual ASEE Conference & Exposition, June 24-27, 2007, Honolulu, HI.
15. Asmatulu, R., Khan, W., Wamocha, H. and Adeniji, A. "Improving the nanotechnology education for future engineers," ASEE Midwest Section 2007 Annual Conference, Wichita, KS, September 19-21, 2007.
16. Alpay, P.S. "Introduction to Structure, Properties, and Processing of Materials II Spring 2007," University of Connecticut, 2007.
17. Asmatulu, R,. Claus, R.O., Mecham, J. B. and S. G. Corcoran, "Nanotechnology-associated coatings for aircrafts" *Materials Science,* Vol. 43, No: 3, 2007, 415-422.
18. Jaksic, N. "Nanoscience, Nanoengineering and Nanotechnology Education at Colorado StateUniversity – Pueblo," Mater. Res. Soc. Symp. Proc. Vol. 931, 2006.
19. Feisel, L.D. and Rose, A.J. "The Role of the Laboratory in Undergraduate Engineering Education," *Journal of Engineering Education*, pp. 121-130, January, 2005.
20. Leva, A., "A Hands-On Experimental Laboratory for Undergraduate Courses in Automatic Control," *IEEE Transactions on Education*, Vol. 64, No. 2, pp. 263–272, 2003.