Integrating Design of Experiments and Writing into a Manufacturing Processes Course

Emmanuel Ugo Enemuoh, Ph.D.
Department of Mechanical and Industrial Engineering
University of Minnesota Duluth
eenemuoh@d.umn.edu

Abstract
The manufacturing processes course taught at the University of Minnesota Duluth is an integration of traditional lecture, writing, and laboratory intensive. The laboratory component focuses on the use of writing and design of experiments to analyze and characterize manufacturing processes. Results and observations from the experiments are presented in a journal format. Plastic injection molding, green sand casting, extrusion, blank shearing, welding, and fiber reinforced composite processing have been taught and implemented in the laboratory using this approach. Students prepare detailed reports in a journal format on any four of the laboratory experiments conducted. In lecture, students learn theory of manufacturing processes, how to design and analyze experiments, and conduct literature review on manufacturing processes in professional journals. For each process, the instructor and students identify significant control process factors and quality characteristics to be investigated. The levels of the control factors are chosen in order not to obscure the influence of a control factor on the measured quality characteristics. This technique of teaching manufacturing processes course exposes students to critical thinking about the fundamental assumptions, discussing calculated results, analyzing plots of data, posing questions about the meaning of definitions, increasing interest in and connection with course material, and becoming familiar with engineering writing conventions.

I. Background

The College of Science and Engineering is a four-year ABET accredited engineering school offering engineering degrees in mechanical & industrial, chemical, computer science, and electrical & computer engineering. The curriculum emphasizes design, manufacture, and automation, while preparing students for careers in industry and continued education. A four-credit manufacturing process course is designed for junior and senior level mechanical and industrial engineering students. The course consists of three hours of lecture and two hours of laboratory work each week. Department of Mechanical and Industrial Engineering has a material processing laboratory equipped with a wide range of traditional manufacturing processes equipment to support its practice oriented, hands-on, design-centered curriculum.

The science of engineering involves understanding how things work in a mathematical fashion. Engineers build mathematical models of reality, but the models are always a simplification of reality. Hopefully, the model will give us greater understanding, but we must be careful that our model has some contact with the reality. We must verify model predictions with experiment and observation. Sometimes even the simplest situations are too difficult to describe with mathematical models. That is why the practice of engineering requires a combination of both art and science. To understand how things work, we must understand the underlying cause-

Previous page View by Title View by Authors Table of Contents

effect relationships. Some of these relationships are too complicated to understand mathematically, but we can still learn about these complex relationships through experience, measurement, and observation. This course deals with manufacturing processes and properties of materials. Hopefully by doing the experiments and writing about the observations, students will gain some information about particular processes, materials, tests, transducers, and instrumentation.

II. Objectives of the Course

This technique is designed so that students will be able perform the following tasks after completing the course:

1. Design and analyze experiments using statistical tools to estimate mean effects of process parameters.
2. Setup and run designed experiments as a team.
3. Discuss and report results in a journal format.
4. Design and analyze various bulk deformation processes.
5. Design and analyze various thermal and mechanical processing methods of metals, plastics and composites.

Objectives 1 through 3 are achieved by formulating a generalized standard laboratory procedure. With this approach, groups of students conduct experiments on the different manufacturing processes using pre-selected process parameter levels. Statistical analytical procedure is then used to evaluate process parameter effects and conduct error analysis. Objectives 4 and 5 are achieved through traditional lecture. Exercises that involve design and analysis are assigned at the end of every manufacturing process topic taught. Examinations are used to further evaluate students' knowledge of the subject.

III. Description of Course

The course has three major components: lecture, laboratory exercises and writing as illustrated in Figure 1.

Lecture

The lecture is used to educate students on the physical fundamentals of processes. It provides a descriptive introduction to a wide variety of options, emphasizing how each process works and its relative advantages and limitations. Mathematical models and analytical equations that describe processes are studied to enhance their basic understanding. The students also study and analyze the influence of manufacturing processes on product quality and properties. Students learn how to design experiments using factorial and fractional factorial designs. These designs are used extensively in industry for factor screening and process characterization.

Description of the Laboratory Exercises

In the laboratory component, students are assigned into groups of four to conduct experimental studies on the three major classes of metal and polymer fabrication processes. They use knowledge acquired from the lecture component to conduct data analysis and characterization of processes. They relate the effects of process parameters on mechanical and physical properties of products. A total of eight laboratory experiments have been designed for this course and they are briefly described below.

Metal Casting Experiment and Solidification Characteristics: Fundamentals of green sand casting processes are explored by studying the effect of surface area to volume ratio on quality characteristics of cast aluminum alloys. A full factorial experimental design with 4 replications is used to study and quantify the effect of surface area-to-volume ratio on casting density. After casting experiments are conducted, Archimedes principle is used to measure casting volumes, densities, and total volumes of internal porosity. The actual density of alloy castings is less than the theoretical density because of internal porosity, which is caused by internal solidification shrinkage and evolution of hydrogen gas during solidification. Analysis of variance is used to explain the effects of casting surface area to volume ratio on solidification rate, effects of solidification rate on internal, external, and total shrinkage volumes.

Injection Molding of Plastics: A vertical injection-molding machine is used to characterize injection molding of thermoplastics. A 1/2 X 2^5 fractional factorial experimental design with 3 replications is used to quantify the effects of 5 independent variables on the part quality characteristics. The independent variables investigated are barrel temperature, nozzle temperature, dwell time, and injection flow rate. The dependent variable measured is part weight, which is correlated with defects and tensile strength of the part.

Blank Shearing of Metals: A 10 ton hydraulic press with a 20,000 lbs. capacity strain gauge load cell is used to study and characterize the plastic deformation and shear failure of metals using punches and dies that punch circular slugs out of different thickness of sheet metals. A 3^2 full factorial experimental design with 3 replications is used to estimate the effects of punch/die diameter and sheet metal thickness on maximum punching force F_{max} and distance over which F_{max} acts on the slug. The force is measured with a strain gauge load cell transducer, and the distance b, is measured with a dial caliper to the nearest 0.001 in.

Heat Treatment of Metals: Aluminum alloy 319 sand casting specimens are heat treated with different procedures and changes in their physical and metallurgical properties are evaluated. The two independent variables investigated are heat treatment condition and surface area-to-volume ratio, with three and two alternate levels respectively. The two dependent variables studied are casting hardness R_E and metallographic observations. The three levels of heat treatment condition are as cast, as quench, and as precipitated. The metallographic observations of heat-treated castings are accomplished by polishing and etching potted specimens. Students are expected to interpret their metallographic observations.

Metal Inert Gas (MIG) Welding: A 2^2 full factorial design is used to study and characterize the influence of shielding gas, carbon dioxide, and joint geometry on the quality characteristics of a welded joint of a mild steel, A36. The quality characteristics investigated are strength of weld joint and weld joint defects. The two levels of joint geometry are straight and angled butt joints. The strength of weld joints is measured by performing tensile test on the weld specimens. The defects on the joints were evaluated by counting number of voids and oxidation per square inch surface area.

Composite Processing: Vacuum bagging process is used to fabricate rectangular composite beams of a polyurethane foam core reinforced with glass or carbon fiber materials. Then a 2^2 factorial experimental design is used to investigate and characterize the effects of fiber material type and number of layers on the mechanical properties of the composite beam. A four point bending test is used to measure the strength and stiffness of the composite beams.

Extrusion of Metals: A 2^2 full factorial design is used to study and characterize the effects of billet length and extrusion velocity on the required extrusion work and force during direct extrusion of lead billets. An ATS tensile testing machine with data acquisition system and LabVIEW software facilitate this experiment. Coefficient of friction and flow stress are also estimated from the experimental data.

Writing

In the writing component, a total of 4 reports are written by students with an engineering journal format describing the experiment objectives, procedures, results, analysis, and conclusions for any four laboratory experiments that have been conducted. A literature survey is conducted by the students to support their background knowledge on the production, physical properties and current research, which has been done on the respective process. On the data analysis and results sections of the report, students must compute and demonstrate the following statistical analysis:

(i) Computation and description of analysis of variance table for the experiment.
(ii) Computation and description of main effects of control variables.
(iii) Computation and description of interaction effects of control variables.
(iv) Formulate process model and conduct residual analysis of the model.

On the discussion and conclusion sections of the report, students must discuss significance of factor effects and interactions between them. They must describe significance of the observed level of experimental error in terms of the engineering properties of the process and material. Also, they will explain the gaps and overlaps that exist between experiment and theory. At mid-semester, a formal final project proposal is submitted by the students and evaluated by the faculty. The proposed final project must include design, analysis and characterization of a manufacturing process using a factorial experimental design having three or more independent variables with replications. Three examples of final projects conducted by the students are:

1. Machinability Characterization of 6061-T6 Aluminum Alloy.
2. Effect of recycling on mechanical and physical properties of molded thermoplastics.
3. Test and Characterization of impact behavior of metals.

IV. Discussion

This approach of teaching manufacturing processes bridges the gap between theory and practice that many students encounter in many engineering programs. The laboratory exercises are designed to maintain the learning interest of students who are more practical than theoretical oriented. In some cases where the lab on a particular process is executed before the lecture, students learn by inductive process, which is a more natural learning style [1]. The approach presented in this paper has its advantages and disadvantages, which may be highlighted as follows:

Advantages:

1. The practical experience of using design of experiments to study, characterize, and optimize different manufacturing processes gives the students a deeper understanding of each process and its parameters.
2. Students develop critical thinking skills as they are challenged to explain the effects of process parameters on mechanical and physical properties of products.
3. Students become familiar with writing conventions of engineering journals.
4. Students improve retention and understanding of course material.
5. Students learn to work and write as a team.

Disadvantages:

1. Increased faculty and student time is required to complete laboratory exercises and evaluation of reports.
2. The cost of running labs is higher since more materials are used to complete experiments.

V. Assessment of Course

The students understood the concepts and how different manufacturing processes work by using this approach, especially, by incorporating laboratory data and writing to describe the underlying cause-effect relationships. The students have provided positive feedback to this learning approach and have shown to have deeper retention of the subject. They have expressed that the writing skill acquired from this course help them in other writing intensive courses.

References

[1] Felder, R.M., and L.K. Silverman, "Learning and Teaching Styles in Engineering Education," Engineering Education 78(7) 674, 1988.

[2] Introduction to Statistical Quality Control, Douglas C. Montgomery, 4th Edition.

[3] Introduction to Manufacturing Processes, John A. Schey, 3rd Edition.

[4] Industrial Engineering Production Processes Laboratory Manual, L.W. Garber, Ph.D., Associate Professor, Industrial Engineering, July 30, 1999.

Biography

Emmanuel Ugo Enemuoh is currently an assistant Professor in the College of Science and Engineering at University of Minnesota Duluth (UMD). He has a Ph.D. in Mechanical Engineering. He has 2 years of college engineering teaching experience as well as 1 year Post Doctoral research experience. His teaching interests lie in manufacturing processes, material science, statistical quality control and non-destructive evaluation methods. His research interest includes machining of composite materials, non-destructive evaluation, and structural health monitoring techniques.

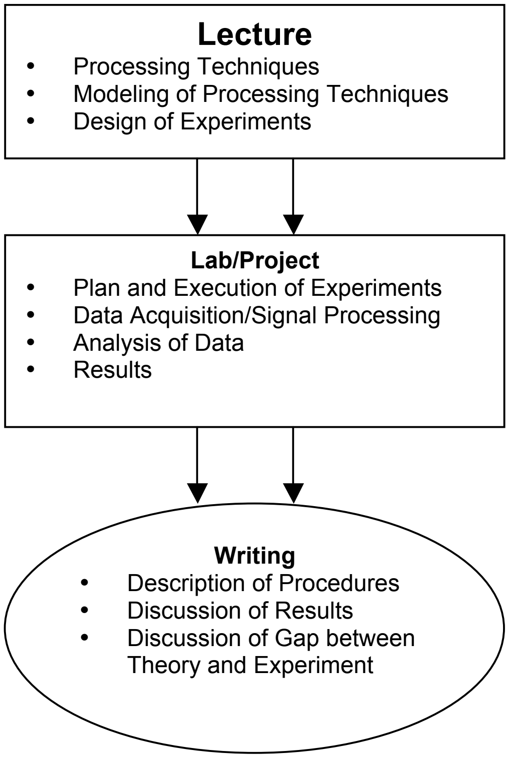

Figure 1 Components of the course