Development of a Design & Manufacturing Course

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ABSTRACT

A Design& Manufacturing course has been developed in which students consider and practice design and manufacturing by proceeding along a path through brainstorming, design, analysis, process planning, manufacture, product testing, and evaluation. Emphasis was placed on design in parallel with manufacture. Course content included properties measurement, analysis for design, prototype fabrication, inspection, testing, and evaluation. Laboratory sessions included creation of a product description, NC pattern machining, casting of dies, injection molding, inspection, and testing. Students worked both individually and in teams. They began with brainstorming and had batches of products ready for testing two weeks before semester's end. Future offerings will include more active leadership through tasks, more review of important concepts from science courses, and clearer communication of expectations.

INTRODUCTION

With the marketplace becoming increasingly competitive as notions of mass production and a serial design process have given way to lean, agile production and concurrent engineering, there is a concomitant need for changes in design and manufacturing pedagogy. It is important for engineering education to have the multi- and cross-disciplinary approaches expected of practicing engineers. Design education needs a perspective of production-related topics while manufacturing education needs an emphasis on manufacturing response to design changes.

The Design & Manufacturing course introduced at R.P.I. in Spring 1995 combined elements of both design and manufacturing education in a new way. This upper-class Mechanical Engineering course gives a vertical exposure to elements of the design-to-production process. It gives the opportunity to combine and apply material from engineering science courses to working a unified set of tasks in which are components of product and process design. Student teams take a design problem and use a single manufacturing process to manufacture a single component product. Course tasks were focused in order to ensure student success while having a broad scope of student experiences and course delivery formats.

SYLLABUS

The syllabus was arranged to give exposure to a variety of disciplines and tasks involved in the design-to-production process. The weekly topics and their format are listed in Table 1. The assignments along with the type of work and disciplines involved are listed in Table 2. A design problem is presented on the first day. The problem is designed to be simple enough that analysis for design is manageable given the technical background of upper class students. The problem is also designed such that solutions can be manufactured with the available equipment. The problem reads as follows:

> *It is desired to have a product which can be inserted into a 1/8" aluminum cover plate to lift it out of its seat. The product can be fastened into the plate from only one side. Once the product is fastened to the plate, it needn't be removed This product will be "gripped" by a clevis hung from the end of a cable. The product should be easily inserted manually into the plate. The insertion hole shape and dimensions in the plate are not specified.The product should fit within a 2" x 2" x 1 1/2" envelope. It should be capable of carrying short-term loads of 300 lb. opposite to the insertion direction, a side load of 150 lb, and a torsional load about the axis of insertion of 30 ft. -lbs.*

Students are formed into teams and assigned to brainstorm for solutions. They then share their results with the rest of the class.

Table 1. Syllabus - Desire& Manufacturing Lab

Week	Subject	Format
1	Design prob.	lect. & discuss
1	Databases	lect
2	Mech. mat'l. behavior	lect. & lab
3	Fastener analysis	lect
3	Design critique	discuss
4	Analysis of design	lect. & lab
5	Analysis examples	lect.
6	NC programming	lect.
7	Molding process design & expts	lect. & lab
8	Analysis of injection molding	lect.
9	Course review, NC machining	lect.
10	Cavity casting	lab
11	Batch production	lab
12	Inspection	lab
13	Testing	lab
14	Results review	discuss

Once teams collected solution ideas, they were asked to select those which were most promising given the processes available (namely, injection molding and NC milling). Injection molding constrains product material and geometry. Material is limited to plastics. Product topography is limited to shapes which can be extracted from a die. Product volume is limited by shot size. Given that the cavity casting patterns are milled, the part concavity is limited by tool diameter. A common solution was a plastic product which snaps into a slot in the plate.

Recent advances have enabled easier materials-related decisions in design and manufacturing [1]. Material database software (MAT.DB, ASM) was used to select materials for applications. Students submitted search strategies and ranked the most promising plastics. Time and molding temperature limits did not permit them to actually use the selected materials. The selected plastic was polypropylene, Pro-Fax 6523 (Himont, DE). This was selected for its low melting point and well-characterized properties.

Each team generated their mechanical properties results. To demonstrate plastic's viscoelastic nature, tensile tests were conducted at various deformation rates. Students come to the course familiar only with linear elastic behavior. This is their first exposure to the concepts of true stress and strain and viscoelasticity. Teams reduced their data in terms of both engineering and true stress and strain. From these, they estimated moduli, the stress and strain at yield (when it existed), and offset yield strength.

To refine the product design, the teams were to make a CAD file of their concept and use mechanical property data along with their knowledge of solid mechanics to analyze product performance. It was expected that the teams would examine their product design under each specified load, decide which types of analyses were necessary, create mathematical models, and iteratively analyze and adjust product dimensions until performance criteria were met. Analysis was to be done with concepts learned in mechanics of materials courses. Numerical analysis approaches were optional. Various plastics design texts were assigned [2,3]. Students were encouraged to also refer to design manuals [4,5]. To simplify the analysis, the plastic was treated as a linear elastic material below the yield stress. Design optimization of was not expected or required.

Table 2. Assignments, Experiences, Previous Courses.

Assignment	Experience	Previous Courses
Preliminary design	Teamwork, Product design	Engr’g. Design
Database Searching	Design-Mat’ls. Interface	
Matyl Properties	Experimentation	-
Cantilever Snaps	Analysis	Mechanics
Product Dimensions	Analysis, Manufacturing	Graphics, Mechanics, Strength of Mat’ls
Part File	Design comm-unication	Graphics
Design Report	Communica-tion, Teamwork	
Cutter Lines	Process design	-
Pattern Machining	Mfg., Rapid prototyping	-
Cavity Casting	Mfg., Rapid prototyping	-
Mold Settings	Analysis, Process design	Fluids, Heat Transfer
Molding	Manufacturing g	Adv. Mfg. Lab
Inspection	Analysis, Measurement	Modeling & Analysis of Uncertainty
Testing	Experimentation	Expt'l. Mech.
Manufacturing Report	Communica-tion, Teamwork	-

Traditional steel injection molding dies are expensive and more accurate and durable than necessary for most academic laboratories. They are also difficult to create on a semester time scale. Prototype molding dies cast from high-temperature epoxy are used instead. To do this, teams design the milling process which creates a casting pattern in the Pro/Manufacture (Parametric Technologies). They can import their design file, select tools and machining parameters, and verify the machining by viewing a cutting animation. The process design result is a cutter line file which is converted to machine control data (MCD) for the milling machine. It is intended that this conversion be as transparent and seamless as possible. The MCD is downloaded from a personal computer.

The machining fixturing doubles as a portion of the casting fixturing. A schematic showing the pattern, plate, and die base plate is shown in Figure 1. The cavity is assembled by coating the appropriate surfaces with parting agents or sealers, and locating the die base with respect to the pattern. Epoxy is then mixed and poured. The epoxy (Ciba-Geigy 4036 resin/1511 hardener) is specifically formulated for prototype mold making. Once cured, the pattern base is removed and the pattern is lifted out.

Prior to coming to the injection molding lab, students prepare estimates of processing conditions for their team’s product. During the lab, students are introduced to the molding machine, run several molding trials in which they examine the effects of variation in critical process parameters (e.g., filling time, packing pressure, and cooling time), and compare their estimates with actual molding conditions. The production lab session begins with installation of the dies into the molding machine. Estimates of clamping force, and injection and packing schedules are prescribed. Shot size is increased until the die is filled. Once an acceptable operating point is reached, a batch of twenty or more products is molded (See Figure 2).

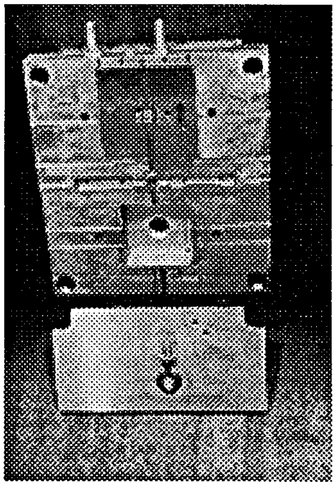

Figure 1. Photograph of wax pattern mounted to the milling/casting plate along side the base plate.

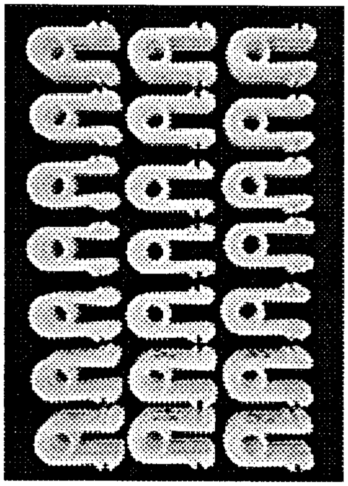

Figure 2. Batch of products manufactured by injection molding in cast epoxy dies

The teams are asked to answer several hypotheses about their product using the results of statistical analyses of product dimensions. They estimated the confidence level appropriate for the particular question. Discussions of statistics were assigned. The text [6] presents statistical concepts in the context of manufacturing and product quality. Dimensions are taken from every product in the batch. The selected caliper transmits readings directly into a spreadsheet using a PC-to-caliper communications utility (Software Wedge, TAL). This cuts lab completion time, reduces mistakes, and gives exposure to communication for statistical process control.

Teams receive first-hand exposure to the relation between design decisions and product performance in the testing lab session. Pull-out, torsional, and side load tests were done. Load, location, and mode of failure were recorded and compared against design specifications.

DISCUSSION

This course offers a unique mixture of individual and team work, design and analysis, and design for performance and manufacture. The course has several threads into the curriculum. The lab sessions involve experiments, prototyping, manufacturing processes, production, inspection, and testing. Students felt stymied in the product design early in the semester. However, they were quite satisfied when the images they had fashioned on the computer monitor became products. They were keenly interested in seeing their products perform.

By going through an entire design-to-production process, the teams were able to reflect on their designs. We focused on a single component product because of the many of detailed analyses which could be done and the breadth of product/process considerations which could be made. Time constraints did not allow a detailed consideration of machining of slots in the plate. The clevis shape was treated as given. Among the primary problems for attaining a good product-to-plate fit was the result of plastic shrinkage and warpage. Compensation for these was beyond the course' scope. However, given the results of injection molding, inspection, and testing, most teams could have corrected their designs and created batches of improved products in a week.

There are areas in which improvements are planned. Most students were not familiar with manufacturing processes. If future course offerings involve selection from manufacturing processes, more time would be spent learning each process. This course might be preceded with one similar to the one developed by Todd [7] in which students research and teach dozens of manufacturing processes to each other.

In the analysis-for-design, it had been expected that teams would feel comfortable to use their own discretion to select their analytical approaches to design. For most, however, this was an unfamiliar environment approached with trepidation and resulting in angst. At mid-semester, the most common complaint was lack of direction. As corrective action, the instructors exercised more leadership in the semester second half. For example, a detailed description of the remaining tasks was given out. The instructors need to anticipate unfamiliarity with open-endedness and be prepared to prompt students into applying what they know from science courses to the design problems at hand. Another future approach will be to give a diagnostic exam at the course beginning to give the instructors an idea of the recall level from previous coursework. Review could then be offered and recommended.

There was competition for the students' time from other courses. However, this was good practice at time management. During the second half of the semester, advice was given each week to clarify expectations. An early lecture or lab session could be spent advising on organizing, planning, and communicating. Dividing students into teams based upon times of availability and desired partners led to an imbalance in skills. Future offerings would require more time flexibility and have teams grouped primarily by skills.

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