A POLYMER PROCESS OPTIMIZATION CENTER: INTEGRATION OF NSF AND INDUSTRIAL SUPPORT

Laura L. Sullivan and Gwan –Y. Lai
Kettering University

INTRODUCTION

The Polymer Processing Laboratory at Kettering University has enjoyed tremendous growth in capability over the past four years. Four National Science Foundation ILI Grants have provided for microprocessor controlled injection molding, stereolithography, capillary and on-line rheometry, and tensile testing. Funding from the Society for Manufacturing Engineering has resulted in the acquisition of mold temperature control equipment and mold flow simulation software. Internal funding has provided for process capability analysis, and industrial support has funded a coordinate measuring machine. Now, integration of this equipment has been endorsed through a $100K donation from local industry for a Polymer Process Optimization Center. With the creation of this Center, all phases of thermoplastic component manufacturing via injection molding will be integrated, from materials selection to tool design to process optimization. Undergraduate students will access this facility (1) as freshman, in one week study of polymer processing within a survey Introduction to Manufacturing Processes course (IMSE 101), (2) in an upper division Polymer Processing course (IMSE 407), and (3) via independent study projects in the area of injection molding for senior level students. Within the framework of the Polymer Processing course, IMSE 407, students will be given the opportunity to take the concept of a part, rendered via a solid modeling program, and transform it to a manufactured, injection molded part. This will involve converting the solid model to a solid tool via stereolithography, researching the materials of interest to be sure that they have suitable viscosity characteristics via rheometry, optimize the mold filling and packing portion of the injection molding cycle via on-line process parameter variation.

DISCUSSION

I. Laboratory Capability

The polymer processing laboratory at Kettering University provides hands-on experience in injection molding, thermoforming, extrusion, and polymer testing. This laboratory contains three injection molding machines with associated auxiliary equipment (process analysis equipment, drying ovens, grinders), two extruders, a laboratory capillary rheometer, an on-line process rheometer, a thermoformer, a Stereolithography Apparatus, an impact tester, and two mechanical test machines (one screw driven and one servohydraulic). This lab serves Manufacturing Systems Engineering students who may choose the polymer processing course (IMSE 407) as one of their two required processing electives. It also serves Mechanical Engineering students who have chosen a plastics cognate, a manufacturing cognate, or an automotive cognate. In addition, all freshmen enrolled in any engineering discipline are required to take "Introduction to

Manufacturing Processes," where one week of laboratory time is spent in the polymer processing laboratory.

Within the polymer processing laboratory, students evaluate polymeric materials, which they have processed under a range of variables and statistically analyze and report their results. The majority of the laboratory experiments focus on the interaction between injection molding process parameters and resultant part quality (as measured by mass, shrinkage, strength, and toughness). Due to the arrival of two microprocessor controlled injection molding machines (purchased via National Science Foundation Grant #DUE-9451979), students can test and verify these interactions with accuracy and precision. New capillary and on-line rheometers (purchased via National Science Foundation Grant #DUE-) allow students to evaluate the viscosity and flow characteristics of any thermoplastic. A process analyzer and its associated sensors (purchased via funding from Johnson Controls, and department capital funds) facilitate the correlation of process parameters and process/part repeatability. Students can experiment with rapid prototyping and rapid tooling via a Stereolithography Apparatus, or SLA (purchased via National Science Foundation Grant #DUE-9552248). CMOLD mold design and mold flow software (made possible by a grant from the Society of Manufacturing Engineers) can assist in illustrating the principles of mold design and allow students to simulate flow in potential designs.

II. Integration of Equipment via a Polymer Process Optimization Center

Students will be follow a series of ten steps to take the concept of a plastic product through to the creation of appropriate tooling and the selection of best process parameters.

Step 1: Material Selection.
Students begin this exercise with a solid model of a hypothetical product and a set of mechanical and physical specifications for this product. Using these criteria, students will identify a short list of potential materials from which to manufacture the product. Based upon their selection(s) they will employ the capillary and on-line rheometers to determine the flow characteristics of their choices and select the material most suitable for their process/part.

Step 2: Mold Design and Flow Analysis.
Here, the students enter the viscosity data provided by the rheometers into CMOLD mold design and flow analysis software on PC platforms within the Center. They design tooling appropriate for their product and the material which they have selected, and then they study the flow of their selected material within their tool. Locations within the tool where residual stresses may occur are identified, and where appropriate, modifications to the tooling are undertaken.

Step 3: Stereolithography and Rapid Tooling.
The rapid prototyping method known as Stereolithography involves the laser initiated polymerization of a liquid resin (known as a photoresin). A 3-D solid model of the tooling created in Step 2 is divided into a series of very thin slices; the model is built one layer at a time as each slice is cured onto the previous. The resin tooling that is created can then be inserted into a steel mold base, bolted onto the injection molding machine. Considerations such as modulus differences between the cured photoresin and steel must be taken, as well as thermal expansion/contraction differences. At this

stage photopolymerization theory is discussed. Warpage and shrinkage of the SLA part can also measured for future reference.

Step 4: Process Analysis / Injection Molding
Students "tryout" their own tooling to manufacture plastic parts. The effects of different process parameters on part quality and process repeatability are now determined. The Process Analyzer allows for real-time measurement of polymer melt temperature and pressure, cavity temperature and pressure, screw position, and hydraulic pressure. Data collected via the Process Analyzer can also be analyzed via on-line Statistical Process Control (SPC) and Design of Experiments (DOE). Limitations to quality and/or repeatability that are due to tooling are noted.

Step 5: Secondary Mold Design and Flow Analysis.
Using information gained in Step 4, students optimize their tooling design to allow for better, more repeatable processing. Modifications may include adjustments to gate type and location or changes in runner diameter or length. Small modifications to product design may also be implemented.

Step 6: Secondary Stereolithography and Rapid Tooling.
Information regarding warpage and shrinkage of the original photoresin mold insert can be incorporated in this phase so that the resulting mold cavity will be more dimensionally accurate.

Step 7: Secondary Process Analysis / Injection Molding.
Having made adjustments in design and stereolithography of the tool, students again use the injection molding machines to manufacture their parts. The SPC and DOE capability of process analyzer is at this time employed to quantify the relationship between process variables and the characteristics of the polymer - as it flows into the cavity, as it cools within the cavity, and after it has been ejected from the cavity. Fine tuning of the process parameters will allow for optimum process repeatability.

Step 8,9: Coordinate Measuring Machine (CMM) and Mechanical Testing.
At these stages, the students use high accuracy measuring devices to quantify shrinkage and warpage within the parts generated in Step 7. They also use mechanical test equipment to measure properties such as toughness, stiffness, and tensile strength for these parts. Focus is directed at how closely these measurements meet specifications, and how repeatable the geometric stability and mechanical properties are for this series of parts.

Step 10: Final Process Analysis / Injection Molding, CMM, and Mechanical Testing.
Students use the process analyzer to make final parameter adjustments for optimum quality and repeatability. Final part geometry and mechanical properties are quantified using the CMM and mechanical test equipment.

III. Faculty/Student Research

Research in the optimization of injection molding and the use of rapid tooling to speed the manufacture of plastic products had grown rapidly over recent years. A facility containing tools to assist in material selection, tool design, rapid tool creation, and process optimization is rare, especially in an undergraduate teaching environment. Applications of these techniques to modern manufacturing are quickly disseminated to industry, through the cooperative work experience that Kettering University students enjoy. The Polymer Process Optimization Center is also becoming a center for research into continuous optimization of injection molding and plastic part manufacturing. Students engaged in independent research and conducting undergraduate theses have in the past year measured and tested methods of improving process and part quality using this facility.

CONCLUSION

The Polymer Process Optimization Center at Kettering University brings together and integrates the use of four major National Science Foundation ILI Grant funded pieces of polymer processing equipment, along with additional equipment provided for by funds from the Society for Manufacturing Engineers, industrial support, and Kettering University capital funds. The primary objective of this center is to provide for the undergraduate education and research into integration of all phases of polymer part manufacturing through thermoplastic injection molding. Because of the cooperative nature of the education at Kettering University, dissemination of knowledge and skills attained by Kettering University students will quickly reach the polymer manufacturing industry. Faculty/student research in injection molding process optimization is also forthcoming.

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BIOGRAPHICAL INFORMATION

LAURA L. SULLIVAN

Laura L. Sullivan, Ph. D. is the advisor for the Kettering University chapter of the Society for the Advancement of Materials and Process Engineering (SAMPE), an officer of the Materials Division ASEE, and is active in SPE, SWE, and SME. The Principle Investigator in two NSF ILI Grants, her efforts in modernizing the polymer processing curriculum have been published and presented nationally.

GWAN –YWAN LAI

Gwan –Ywan Lai, Ph. D. is an active member of the ASME, ASM, SME, and SPE. He has taught seminars in Injection Molding, and has consulted in the area of polymer processing for 3M, DOW Chemical Company, and Dynisco. Professor Lai is the Principle Investigator in a National Science Foundation Laboratory Improvement Grant, a Brown & Sharpe Equipment Grant, and an internal Kettering Research Initiation Grant.