LABORATORY AND ON-LINE PROCESS RHEOMETERS FOR THE POLYMER PROCESSING LABORATORY

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INTRODUCTION

Rheological (flow and deformation) properties are the most important factors affecting the microstructure of polymers, critical process parameters for production/processing, and subsequent product quality. To provide students with hands-on experiences in learning and evaluating the rheological properties of polymers, the Polymer Processing Laboratory at the Kettering University/GMI Engineering & Management Institute has acquired a set of computer-instrumented Laboratory Capillary Rheometer (LCR) and On-Line Process Rheometer (OLPR) manufactured by Goettfert through the support from the National Science Foundation (NSF ILI-IP program grant DUE-9650687) in 1996. LCR has long been used as a major tool to measure rheological properties of resins in the plastics industry [1-7], while an increasing number of resin manufacturers and processors are adding OLPR to their process to produce consistent materials and reduce manufacturing costs by monitoring and controlling rheological information during production and processing [8-11]. Through the addition of the LCR and OLPR to the Polymer Processing Laboratory at the Kettering/GMI our students not only can measure the rheological properties of polymer samples through laboratory testing but also monitor the rheological properties of polymer melts directly taken from the process stream of a production line. Both the LCR and OLPR are instrumented with state-of-the-art computer technology which enables them to achieve tasks such as controlling test procedures, collecting and analyzing rheological data, generating material functions, and performing statistical process control and statistical quality control [12,13].

CURRENT PROGRESS

The LCR has been installed and demonstrated to students from IMSE-101 Manufacturing Processes, IMSE-370 Engineering Materials, and IMSE-407 Polymer Processing since the fall of 1997. In addition to the NSF funding, two more capillary dies used with the LCR were purchased through a 1997/98 SME grant and a new extruder for the OLPR was purchased through a departmental capital fund. The OLPR is installed on the extruder through an adapter and a supporting frame designed and constructed on site. Laboratory experiments for both rheometers have been developed to allow students to experimentally investigate and observe the rheological phenomena of plastics through laboratory testing and on-line process monitoring. IMSE-499 Independent Study students in the winter and spring of 1998 have first investigated and run these experiments and provided feedback to improve/modify the experimental procedures. These experiments will then be used in the IMSE-370 and IMSE-407 starting from the summer of 1998. The rheological data will be collected and sent to a Polymer Process Optimization Center (see next page) for material characterization, mold flow analysis, process optimization, and quality control. The LCR and OLPR have been used in a continuing education course, *Modern Manufacturing for Educators*, for high school and community college teachers. They will also be used in pre-college science and engineering programs hosted by Kettering/GMI faculty for junior high and high school women in the summer of 1998. In addition, the LCR and OLPR will provide students with opportunities for conducting undergraduate research and independent study, and publishing theses and papers. Evaluations of student performance and satisfaction will serve as the first mechanism of project evaluation, and will be reported to the academic and industrial community via publications and presentations following the present one.

Polymer Process Optimization Center

Over the past four years, commitments from the IMSE department, the National Science Foundation, the Society of Manufacturing Engineers, and local industries have allowed for the modernization of the Polymer Processing Laboratory at Kettering/GMI. In addition to the LCR and OLPR which allow students to evaluate the viscosity and flow characteristics of polymers, (1) two microprocessor controlled injection molding machines (purchased via NSF grant #DUE-9451979, L. L. Sullivan and W. F. Erevelles) allow students to investigate the interaction between injection molding process parameters and resultant part quality, (2) a process analyzer and its associated sensors (purchased via funding from Johnson Controls and departmental capital funds) allow for the correlation of process parameters and process/part repeatability, (3) a stereolithography apparatus (purchased via NSF Grant #DUE-9552248, L. L. Sullivan and W. F. Erevelles) allows students to experiment with rapid prototyping and rapid tooling, (4) CMOLD mold design and mold flow software (made possible by a grant from the Society of Manufacturing Engineers; G.-Y. Lai and L. L. Sullivan) assists in illustrating the principles of mold design and allows students to simulate flow in potential designs, and (5) a coordinate measuring machine (obtained through a Brown & Sharpe Metrology Equipment Grant Award, G.-Y. Lai, W. F. Erevelles, and L. L. Sullivan) allows students to investigate the shrinkage/warpage and dimensional stability of injection molded parts to verify and control product quality.

The next step in providing quality education in polymer processing at Kettering/GMI is to furnish students with the opportunity to integrate the above equipment and all phases of plastic part manufacture. To allow for this integration, L. L. Sullivan and G.-Y. Lai have successfully received a five-year donation of $100,000 from Textron Automotive Company in Troy, Michigan to establish a Polymer Process Optimization Center. This center is currently under construction and will house one Windows NT network sever and five NT workstations: (1) to receive, analyze, and transmit data between equipment (LCR, OLPR, process analyzer, testing equipment, and injection molding machines) within the Polymer Processing Laboratory, (2) to run the CMOLD software, (3) to interface with the Stereolithography apparatus, allowing for the conversion of a solid model to an actual mold insert, and (4) to control and communicate with the coordinate measuring machine to allow for automated dimensional inspection and quality control.

The LCR and OLPR play a very important role in supporting the Polymer Process Optimization Center by providing the fundamental material functions and properties of polymers to help control resin quality, fine tune manufacturing processes, simulate, predict, and control molding processes, and monitor and control product quality.

LABORATORY EXPERIMENTS

Laboratory experiments are developed and emphasize on (a) material characterization by rheological properties, (b) theory and practice behind the LCR and OLPR, (c) computer-instrumented technology, (d) process monitoring and control, (e) processability and recycling of polymers, (f) effects of rheological properties on processing and product quality, (g) application of statistical techniques, and (h) integration of the LCR/OLPR with the Polymer Process Optimization Center and the CAD/CAM/CAE/CIM environment at Kettering/GMI. The following experiments are developed and tested in the IMSE-499 Independent Study and will be used in the IMSE-370 Engineering Materials, IMSE-407 Polymer Processing, and a new Advanced Polymer Processing course under development.

Experiment 1: Characterization of Polymeric Materials

Objective: Students use the LCR to measure fundamental rheological properties of both commodity and engineering polymers.

Experiment Performed: Students use this computer-instrumented capillary rheometer to determine (a) the viscosity of polymeric materials from measurements of flow rates and pressure drops across a capillary tube, and (b) the elastic properties (the first and second normal stress difference functions) of the materials.

Expected Results: Students learn how to use the LCR to characterize polymers in terms of rheological properties. Students will understand (a) the behavior of Newtonian and non-Newtonian materials, (b) the shear rate- and temperature-dependence of polymeric properties, (c) the relationship between properties and melt flow index, molecular weight, and molecular weight distribution, and (d) the application of computer technology in improving material property measurement, data interpretation, and data visualization.

Experiment 2: Operating Principles of Laboratory Capillary Rheometer (LCR)

Objective: Students learn the principle and practice behind the LCR, and measure and observe the material behavior.

Experiment Performed: Students (a) design and write their own test routines to control the LCR using the computer and its operating program, (b) analyze various polymers, observing flow instabilities, relaxation and thermal stability, (c) analyze and interpret the collected data under different test conditions, and (d) relate the experimental results to viscoelastic behavior and capillary rheometer's operating principle.

Expected Results: Students learn (a) the programming and operation of the state-of-the-art computer-instrumented capillary rheometer (b) the design, planning, and execution of rheological properties testing, (c) the elastic nature of polymers which cause extrudate swell and "melt fracture" or flow instability, (d) Rabinowitsch correction for power law fluid and Bagley correction for capillary entrance pressure drop, and (e) the interpretation of capillary rheometry data and its application to common polymer processing operations such as injection molding and extrusion processes.

Experiment 3: Operating Principles of On-Line Process Rheometer (OLPR)

Objective: Students learn the principle and practice behind OLPR, and monitor the behavior of various polymers during an extrusion process.

Experiment Performed: The OLPR is mounted on the new extruder. Students (a) use the computer and operating software to control the OLPR for various test sequences, (b) compare the OLPR with the LCR in terms of their construction, die geometry, and operating principles, (c) use the OLPR to measure the rheological properties of the same polymers used in Experiments 2, and compare the results from both the OLPR and the LCR, and (e) comment on the applications of using OLPR as a process monitoring and control tool.

Expected Results: Students (a) learn the similarities and differences between LCR and OLPR, (b) learn the pros and cons of LCR and OLPR, (c) understand the capability of OLPR to serve as a process monitoring and control tool.

Experiment 4 : Effects of Processing Parameters on Melt Rheology and Part Quality

Objective: Students learn the effects of processing parameters on the rheological, mechanical, and physical properties of extruded products using the OLPR and statistical techniques.

Experiment Performed: Students (a) run the extruder at different processing parameters by changing the barrel temperatures, screw rotational speed, extrusion pressure, and die geometry, (b) use the OLPR to subsequently monitor the response of rheological properties to these processing conditions, (c) test the mechanical strength and physical properties of the extruded product, (d) use statistical methods such as design of experiments to analyze the effects of processing parameters on the rheological properties of melts and on the mechanical/physical properties of the final product, (e) determine the optimal processing conditions, and (f) use the statistical results and monitored rheological information to control the extrusion process and produce parts with desired consistent quality.

Expected Results: Students learn (a) how rheological properties closely tie to the molecular structure of a plastic during processing and therefore affect the physical and mechanical properties of the plastic product, (b) how to use OLPR and statistical methods to determine optimal processing parameters, (c) how to use OLPR as a means of quality control, and (d) how to use monitored rheological information to control extrusion process using SPC/SQC techniques to guarantee consistent processing history and part quality.

Experiment 5: Processability of Polymeric Composites with Recycled Content

Objective: Students investigate the processability of polymer systems filled with Post Consumer Recycled (PCR) materials and reground resins.

Experiment Performed: Students (a) use the extruder with a circular die to mix virgin resins with reground and PCR materials, (b) palletize the extruded polymer composites using a grinder, (c) run the extruder, using the OLPR (and also the LCR for the palletized resins) to investigate the rheological behavior of the polymer composites, (d) determine the processability of the various polymer composites, and (e) analyze the effects of reground and PCR additions to processability and final part quality.

Expected Results: Students learn (a) the importance of recycling, (b) the processability of recycled materials and their final part quality, and (c) the relationship between rheological information and degradation.

Experiment 6: Integration of CAD/CAM/CAE and On-Line Process Rheometer

Objective: Students establish rheological property database for various available polymers. The database is then incorporated with the C-Mold Software (purchased from AC Technology through a SME grant) to simulate the injection molding process.

Experiment Performed: Students (a) measure the rheological properties of various polymers and store them in electronic database format using both the LCR and OLPR, (b) establish mathematical expressions, i.e. material functions, for the rheological properties, (c) transport the material functions obtained from the local computer of the LCR or OLPR to Kettering/GMI's computer network system, (d) incorporate the material functions with C-Mold Software to simulate the injection molding process, (e) actually mold parts with the various polymers, and (f) compare the results from simulation and actual moldings.

Expected Results: Students (a) learn the integration of the LCR/OLPR with a CAD/CAM/CAE system, and (b) understand the importance of a reliable material database to both the actual injection molding processes and their corresponding computer simulations in terms of mold filling, packing, cooling, and final dimensional quality and stability.

CONCLUSION

The addition of the LCR and OLPR greatly enhances both the materials engineering and polymer processing programs in the Manufacturing Systems Engineering curriculum at Kettering/GMI. It directly impacts students enrolled in the following two courses: Engineering Materials and Polymer Processing. Data provided from the LCR and OLPR is beneficial to all courses in which discussions focus upon the relationship between the rheological, physical, and mechanical properties of polymeric materials, such as Material Characterization, Polymer Science, Adhesive Technology and Applications, and Industrial Painting Technology. The LCR and OLPR provide students with material testing and process monitoring tools which make them even more valuable to their co-op sponsors and future employers. The LCR and OLPR play a very important role in establishing and supporting the new Polymer Process Optimization Center by providing rheological properties of polymers. Laboratory experiments are designed and presented. Further experimental experiences and results will be presented when they become available.

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BIOGRAPHICAL INFORMATION

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Gwan-Ywan Lai, Ph.D. is an active member of ASEE, ASME, SME and SPE. He has taught seminars in Injection Molding and Metrology, and has consulted in the areas of polymer processing and materials for 3M, Dynisco and ErgoTech. He is the principal investigator in an NSF ILI Grant, a Brown & Sharpe Equipment Grant, and an internal Kettering Research Grant.

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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. She is the principal investigator of two NSF ILI grants and her efforts in modernizing the polymer processing curriculum have been published and presented nationally.