Computer-Aided Design for Dimensional Stability of Injection Molded Fiber-Reinforced Polymers

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INTRODUCTION

Recent advances in computer-aided design (CAD) has led to the development of new exercises in the senior undergraduate Composite Materials Processing course at Michigan State University. Here, students were able to manufacture injection molded parts experimentally in the lab and replicate their results with a simulation tool, Moldex3D, allowing for a more intimate understanding in how each processing parameter effects the final part quality.

In injection molding, molten polymer is forced into a mold, cooled and then ejected in the shape of the desired part. However, many processing conditions such as injection time, pressure and addition of filler such as glass fibers may lead to product deformities, reducing overall part quality.

With more curriculums taking an increased interest in the inclusion of computational aides, the workshop developed here provided students with the knowledge to design, acquire and interpret simulated results using various processing conditions in a timeframe which would be impossible to complete in a semester of laboratory experiments.

COURSE DESCRIPTION

The Composite Materials Processing course is a senior level technical elective offered at Michigan State University where students learn the fundamentals to polymer processing. The course consists of two 1-hour lectures and one 3-hour lab each week. During the lab, students gain hands-on experience with injection molding, compression molding and extrusion of fiber-filled and fiber-free polymers.

LEARNING OBJECTIVES

Students had the unique opportunity to couple experimental procedures with simulations allowing students to vary:
•Processing conditions: fill/pack time and mold temperature
•Mold geometry: circular gated disc and a thin rectangular bar
•Material type: thermosets and thermoplastics
•Fiber weight fraction: unfilled vs. filled polymer

Students were assessed on their understanding of how these parameters controlled final part quality based on two metrics: Shrinkage and Warpage. Shrinkage is considered the difference of diameter between the part and mold. Warpage is the degree of bowing in the part.

WORKSHOP DEVELOPMENT

Day 1 (1 hour)

- General overview of Moldex3D and computational fluid dynamics (CFD) solvers
- Brief introduction to meshing, part design, gate design and cooling systems
- Demonstrated how to set up a problem in Moldex3D and <u>obtain a working solution</u>
- Brief overview of post-processing results: Fill, Pack, Cool, and Warp stages

Day 2 (1 hour)

- Held an open discussion for any problems that students encountered (i.e. user errors, machine errors)
- Went over a detailed discussion for post-processing results

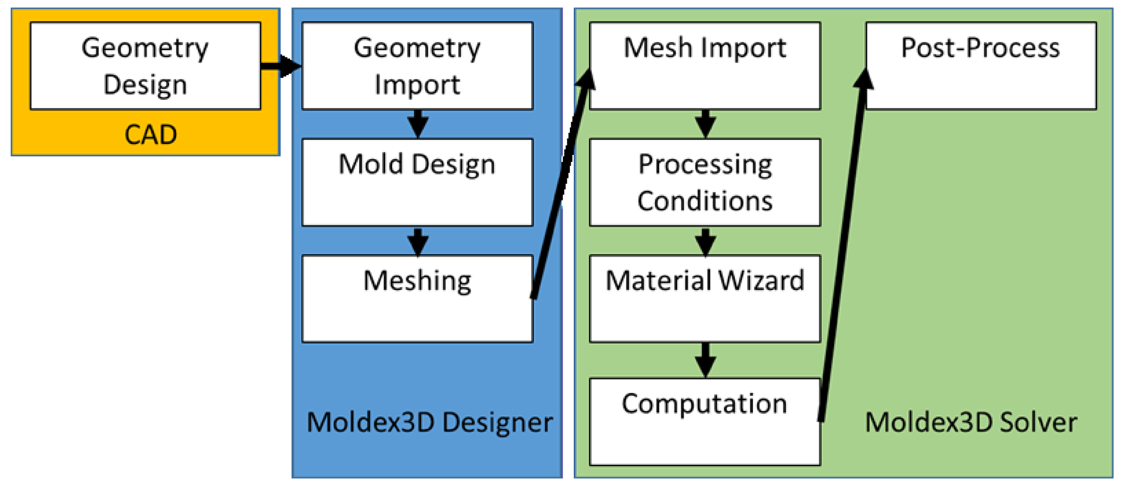
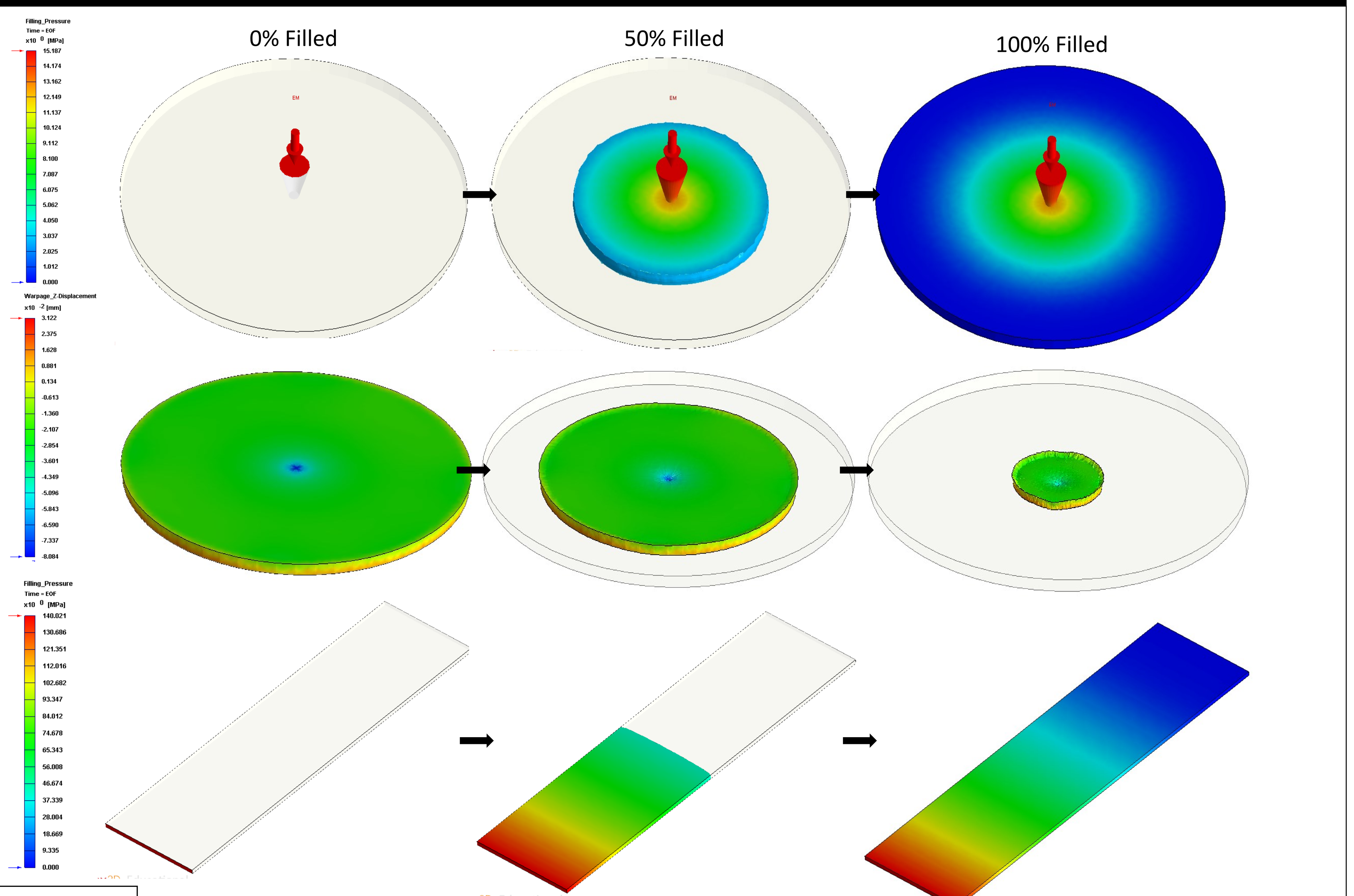


Figure 1. Workflow diagram used in workshop. CAD shown for illustrative purposes with actual geometries and meshes provided to students for simulation.

RESULTS AND DISCUSSION

Figure 2. (Above) Morgan Press Injection molding machine used by students in the laboratory.



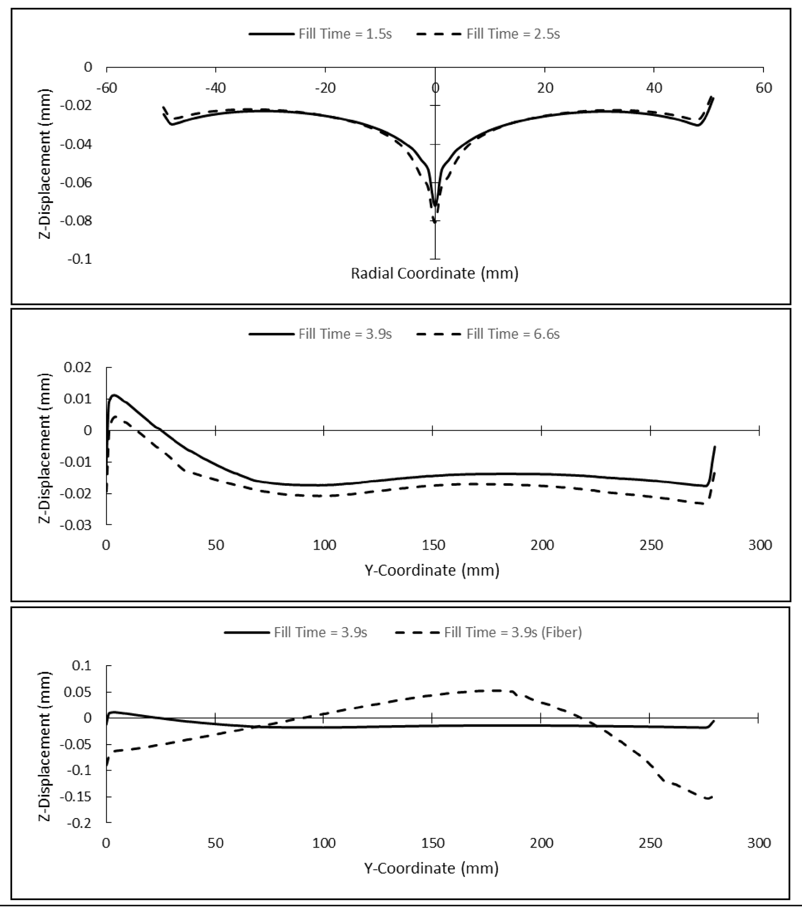


Figure 3. (Above) Simulated results generated by the students (see problem statement) for a center-gated disc and edge gated rectangular bar:
(Top Row) Flow profile showing filling pressure and flow direction; a feature only observable through simulation. **(Center Row)** Warpage results for the center-gated disc. The progression shows an amplification factor detailing exactly where the deformation occurs the most. This proves useful for parts where deformations are small. **(Bottom Row)** Simulated flow profile for an edge-gated disc. This was not done in the laboratory showing the power that simulations have in expanding the student's exposure when time or resources prevent the use of experimental observations.

Figure 4. (Left) Sample of student work detailing the quantitative assessment of warpage in the simulated results. **(Top)** Comparison of fill time in the warpage of a center-gated disc. **(Middle)** Comparison of fill time in the warpage for edge-gated bar showing greater warpage with longer fill times. **(Bottom)** Effect of fiber addition in the polymer on the warpage of an edge-gated bar showing an large increase in the warpage of fiber-filled parts.

PROBLEM STATEMENT

Below is a summary of the questions asked for students to complete independently using the Moldex3D software:

Question 1

1. Using pure polymer, investigate the developing flow fields in different part geometry (disc and bar) (Fig 3-4.)
2. Adjust the fill times for each part and relate how features such as pressure gradients affect part shrinkage/warpage (Fig. 4 Top/Middle)

Question 2

1. For the bar alone, incorporate glass fibers into the polymer and investigate its effect on part shrinkage/warpage (Fig 4. Bottom)

Note: Fiber orientation must be solved numerically

CONCLUSIONS

Students enrolled in the senior level Composite Materials Processing course were introduced to a suite of computational tools to complement their laboratory experiments. During this experiment, each group was asked to investigate the effect that fiber-filled and fiber-free polymers had in the product quality of a circular disc.

A two-lecture workshop was developed for the class to teach the injection molding simulation suite, Moldex3D. An identical mesh of the center gated disc created in lab was provided to each student where they were asked to vary the processing conditions:

- Fill/Packing time
- Injection Pressure
- Fiber Weight Fraction

Since the simulation used an identical geometry and material as used in the lab exercise, students had the unique opportunity to make direct comparisons between simulation and experiment.

Each student generated a report describing the effect that each variation had on the overall product quality based on the shrinkage and warpage metric.

Given that students had molded only circular discs in the lab, it is clear that the incorporation of computational tools allows for not only direct comparisons to experiments, but broader generalizations of observable trends.

ACKNOWLEDGEMENTS

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