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Introduction and Background

As the drafting board has given way to the computer monitor, the role of the product designer has become more integrated with the work of the engineering analyst. Today the language of product design is based on solid modeling. Solids permit tight integration of product design and analysis (Walker & Cox, 1999). Over the past several years there have been many developments that integrate CAD geometry with engineering analysis. Three examples are: "Working Model" for kinematics by MacNeal-Schwendler (MSC Software Corp.), "InCAD" for stress and strain analysis of solids by Algor (Algor, Inc), and "Quickfill" for injection molding by C-MOLD (C-MOLD).

For products that are to be injection molded, the question that should be answered early in the design cycle is, "Can this product be molded?" The advent of user-friendly analysis programs, based upon the integration of analysis with solid-model data, permits a designer to evaluate not only the form and function of a design but also the manufacturability of that design very early in the design cycle (Brickley & Johnson, 1996). With simulation replacing much of the prototyping of the past, computer-based engineering analysis has dramatically reduced the rework involved in product design and, thus, the time and cost of production (Wigotsky, 1997; Maniscalco, 1997). The use of such analysis programs by product designers is one of the latest developments in the time compression trend within manufacturing.

Purpose

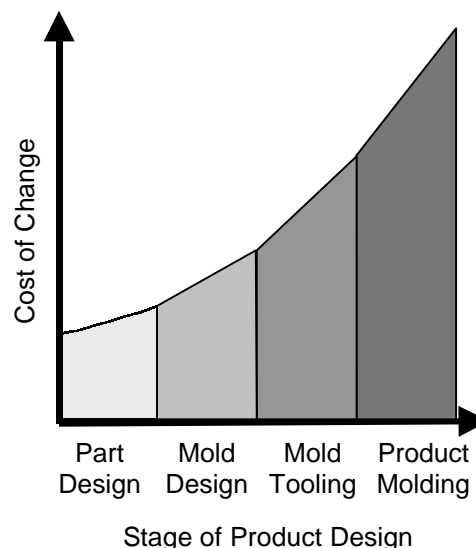
This article will highlight some of the technology that is changing the role of product designers. Analysis tools, which until recently have been the domain of the engineering specialist, are becoming fully integrated with the solid-model-based computer-aided drafting (CAD) programs used by designers. Consequently, product designers are assuming part of the role of engineering analysts. Streamlined engineering analysis programs that can be used by non-specialized designers running CAD on standard PC platforms facilitate this "desktop CAE" (computer-aided engineering). There has been a steady increase in the use of such programs. The growth of the CAD/CAM/CAE market is projected to be more than sixteen percent during 1999 (Daratech, 1999). Within an academic setting, desktop CAE programs are useful teaching tools for both product design and manufacturing processing. These simulation programs are accessible

to educational institutions through vendor educational discounts. This article will illustrate how desktop simulation of injection molding can be used in a manufacturing technology curriculum. Molding simulation can be used to teach plastic product design for manufacturability as well as plastics processing fundamentals. Through simulation, students are able to visualize aspects of the processing that are not apparent. Student projects are used to illustrate what can be done with desktop simulation.

Why Desktop Simulation for Designers

The cost of modifying a molded plastic product increases significantly as one moves from the product design to the mold design and then to the tooling fabrication stages, as illustrated in Figure 1. If it is found that the product cannot be molded as designed, the

Figure 1. Design Cycle Cost Curve



retooling of a mold may be necessary. This process is costly and time consuming. If design for moldability is addressed early in the design cycle, much time and resources can be saved. Designing for moldability of plastic products is possible with newly developed desktop simulation programs available from two major vendors of simulation software: “Quickfill” by C-MOLD (C-MOLD) and “Part Advisor” by Moldflow (Moldflow Corp.).

How Desktop Molding Simulation is Done

Desktop computer-aided engineering programs can be accessed by either a button push within a CAD program or by running a separate program that reads solid-model data exported from the CAD program. In both cases, the geometry information used by the analysis program is based upon the solid model data generated by the CAD program. Traditionally, the product geometry used by molding simulation programs had to be generated independently of a CAD program. The ability to use the solid model geometry of a CAD program has greatly streamlined the geometry input stage of molding simulation programs. Desktop CAE software also simplifies the number of processing variables required by more rigorous analysis programs. The complexity of the analysis is limited in order to make the user interface manageable by the non-expert. The graphical user interface of desktop analysis software is written for application-oriented individuals. Inputs are tailored to match real world control parameters, that is, choice of resin, target filling time, available injection pressure, mold and melt temperature.

The designer begins with a solid model of the part. This may be rendered in any solid modeling program that can export an STL file. The part geometry exported as an STL file is then imported by the desktop analysis program, as diagrammed in Figure 2. Injection molding simulation programs use the part geometry to define the mold cavity. Once in the simulation program, the STL mesh information is used to generate a compatible plastic melt flow model simulating the mold cavity, i.e., a

finite element mesh. The mesh generation is done without user intervention.

In preparation for the simulation, the designer selects an injection point that is likely to yield an acceptable filling pattern. This is accomplished with a simple click of the mouse while positioning a cross-hair over the desired location. Then, the designer selects from a drop down menu the type of resin to be used. Processing conditions can also be specified by the designer. The default values for resin melt temperature and mold temperature are mid-range values recommended for the resin selected. The injection rate may also be automatically computed by the simulation program based upon the part geometry and the chosen gating locations, i.e., points where the plastic enters the mold cavity.

The number and location of gates used to fill a mold cavity have the greatest influence on whether that part can be molded. It is common practice to examine a number of gating options to optimize the filling pattern. During the preliminary stages of design, a designer simply selects a point on the solid model to define a gate. Figure 3 illustrates two gating options, labeled A and B, for a telephone cradle design. Option A would generate one molding trial and option B another. Gating option B allows the part to be molded with less pressure than option A. Option A will yield a better placement of weld lines than option B. The preferred gating is determined based upon the relative importance of the molding pressure compared to the weld line locations for this part. The simulation of the filling pattern for a typical product may take from five to twenty minutes depending upon the product complexity and the available computing power. The rapid feedback in these programs makes them easy to use for multiple product design and gating iterations.

After a product design is shown to be moldable with a given gating option, a delivery system may be added to the mold cavity model to better model the flow of plastic into a cavity that has more than one gate. The addition of the delivery system would be done with the same CAD program that generated the product geometry. For gating option B in Figure 3, the delivery system consists of a sprue,

a runner, and gates, as shown in Figure 4. The point of injection for gating option B in Figure 4 is B*, the tip of the sprue.

What Simulation Delivers

Simulation outputs typically include the pattern of material flow into the part cavity, cavity pressure, and melt-flow temperature. Outputs are summarized with color contour plots on the solid model. In addition, after each simulation a report is automatically generated that summarizes key factors of the product design that may have adversely affected molding. Such factors may be large

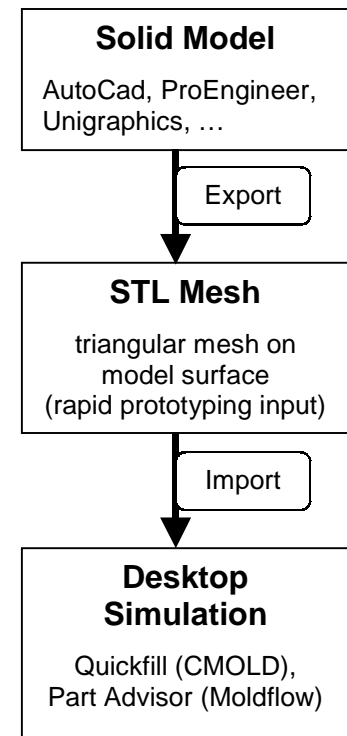


Figure 2. Model Data Flow

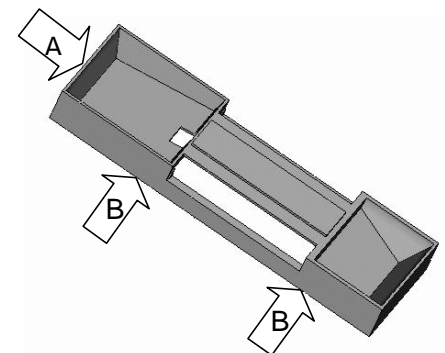


Figure 3. Gating Options for Quickfill Model of Part

variations in product wall thickness or relatively thin wall thickness for the gating option and material selected. For a given gate location, the simulation informs the user of the success of filling the part by displaying an animated melt-flow history. If a short shot occurs because of poor gating, inadequate processing, or poor product design, the program informs the user of the possible causes of the error and how to remedy them. Table 1 summarizes the key outputs from desktop injection molding simulation that help the designer optimize the product shape and the gating choices.

A Tool That Teaches

Desktop simulation is used not only to optimize product design for manufacturability, but the analysis tool can also teach designers the basics of good plastic product design. Lessons learned through failure are often well learned. A failure to fill a part cavity due to poor product design during a simulation is much cheaper than a failure while attempting to mold products. Thus desktop CAE is an ideal supplement to a product design curriculum and to a manufacturing processing curriculum. This past year students enrolled in plastics technology courses at Illinois State University (ISU) have used the desktop simulation program Quickfill by C-MOLD to learn about process optimization. The simulation program taught students through “soft experimentation” how the gate location affects weld line formation, mold vent locations, and the pressure necessary to fill a mold cavity. In the Spring 2000 semester, Quickfill will be used in two product design

related courses at ISU. Students learning product design of plastic parts can study the effect of part thickness and gate location on the moldability of their design. Because the Quickfill simulation also computes the clamp force required to mold a product, students can be made aware of how this affects machine size and, thus, the economics of production.

Simulation in a Manufacturing Curriculum

An example of a student project illustrates what can be done with simulation software. In this case a student examined the effect of processing conditions on the filling of the family mold in Figure 5. The figure illustrates the Quickfill model of the mold cavity that makes a set of tensile, flexural, and impact test specimens. This mold is a family mold because each part cavity is unique. To complicate matters, the disk is only 0.040” thick and the small dog bone is only 0.060” thick compared to the 0.125” thick test specimens to the far right and left sides of the mold. This mold is used to make test specimens within the Plastics Technology Lab at Illinois State University.

The student set out to evaluate the ability of the Quickfill program to simulate a short-shot condition, a molding failure caused by the incomplete filling of a mold. The injection pressure and the injection speed of an injection molding machine were set to cause an incomplete filling of the tensile specimen mold cavity. The machine settings were input to the simulation program and a short shot was predicted that closely matched the observation. A

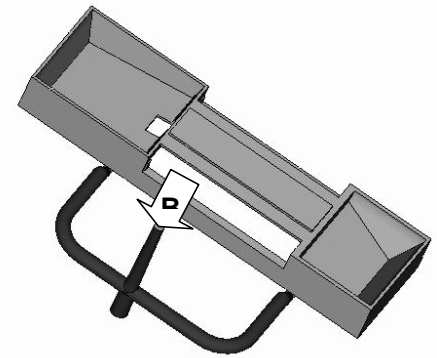


Figure 4. Delivery System Modeled for Option B of Figure 3.

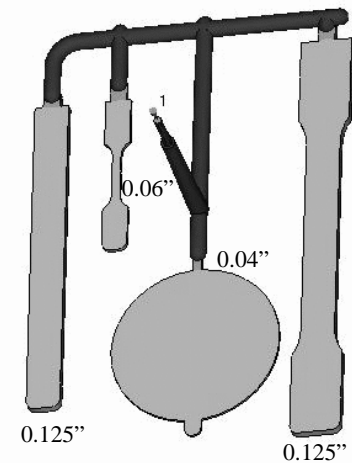


Figure 5. Quickfill Model of Test Specimen Mold

Table 1. Key Outputs from Desktop Injection Molding Simulation

Output	Design Importance	Outcome Affected by
Melt Flow History	Moldable product	part geometry, gate location
Weld Line Locations	Cosmetic, reduced strength	part geometry, gate location
Vent Locations	Mold design	part geometry, gate location
Short Shot (incomplete filling)	Part not moldable	processing, gate location, part geometry, material
Sink Marks	Cosmetic	part geometry, processing, material, gate location
Cavity Pressure	Determines clamp force	wall thickness, gate location, processing, material
Clamp Force	Machine size, molding economics	cavity pressure, product size

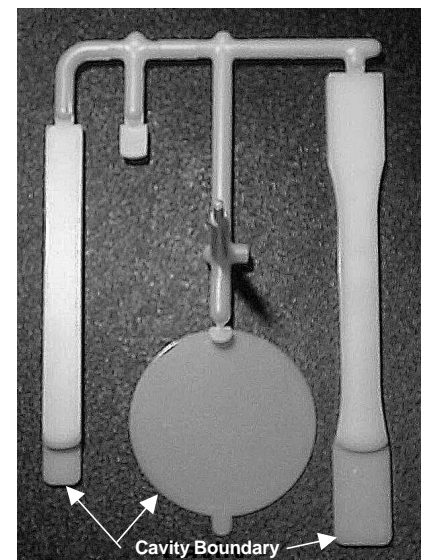


Figure 6. Actual Short Shot - Slow Filling

photo of the molded short shot is shown in Figure 6 and a plot of the simulation result for filling is given in Figure 7.

To test the ability of the program to predict changes in the filling pattern due to changes in processing, a second set of moldings was done with a higher injection speed. Higher injection speed should permit the disk to fill more before freezing. The molded parts demonstrate this fact as shown in the Figure 8 photo of the second molding trial, molded with a faster filling rate. The simulation outcome is depicted in Figure 9. The simulation predicts the additional filling of the disk compared to the first case shown in Figure 7. The other notable outcome is that the filling patterns resulting from specified process conditions of injection speed and limited injection pressure were rather well-predicted. The discrepancies can be attributed to inaccurate material model data. The simulations were performed with a generic polystyrene material model, not one measured for the resin used in the actual moldings.

This case history illustrates the potential for using a program like Quickfill to teach injection-molding troubleshooting. The family mold studied in this case represents a classic example of flow hesitation. The thin disk cavity begins to fill early during the molding. However, due to the higher flow resistance of the disk, the melt flow stops advancing into the disk and proceeds to flow into the thicker sections of the mold. Consequently, the thin disk begins to solidify before the mold cavity fills. The result is an incompletely molded product. A change in the gate location of this family mold would facilitate the filling of the disk. The failure of the family mold to fill is a lesson in mold design as well as in product design. A product designer can learn a basic rule of good plastic part design from this case, that plastic products should have uniform wall thickness to avoid flow hesitation.

Finally, desktop simulation fosters a better understanding of the injection

molding process. In the case of injection molding, the flow of the plastic inside the mold goes unseen. Simulation provides a way of seeing the process of injection molding. Simulation also permits a student to observe phenomena that would be very difficult to measure, such as shear heating and pressure variation inside the cavity.

Conclusion

Desktop injection molding simulation programs are not only useful to determine if an injection molded product can be molded, they can also teach designers about the basics of good plastic product design. Simulation offers students within a manufacturing curriculum a new window into what takes place during injection molding. The use of desktop simulation in the manufacturing curriculum at Illinois State University is part of an ongoing effort to provide a state-of-the-art learning environment in product design and plastics manufacturing. It is the author's belief that as preparation for a career in product design, students within an industrial technology program benefit from exposure to these new and rapidly growing applications.

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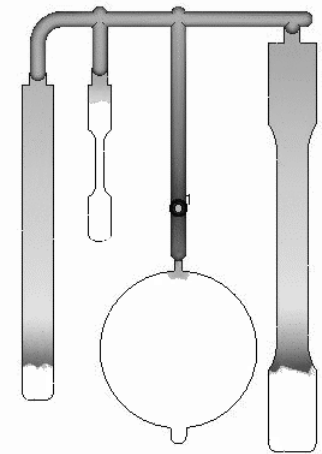


Figure 7. Quickfill Result – Slow Filling

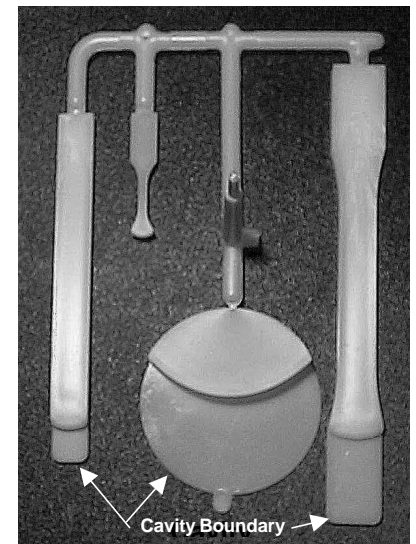


Figure 8. Actual Short Shot – Fast Filling

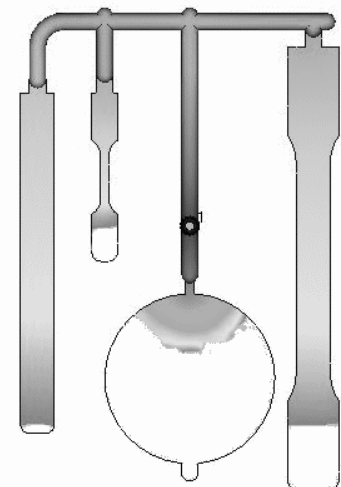


Figure 9. Quickfill Result – Fast Filling