Utilizing Manufacturing Process Simulation Tools as Instructional Aids

Arif Sirinterlikci, Shah Galib Habib
Ohio Northern University / Hewlett-Packard Company

Abstract

Engineering numerical analysis software has been utilized in design of manufacturing processes, parts or tooling by major manufacturing companies. These tools have become available to smaller companies with the advents in computers. Even though cost of most software is still much greater than cost of a computer with great capacity, software involvement is becoming more and more common in manufacturing design process. On the contrary, cost is not an issue for academic institutions since many software companies have educational programs offering drastic price reductions.

This study presents a general manufacturing process course utilizing manufacturing process simulation tools as instructional aids. The objective of the course is to accomplish intelligent use of the software tools in learning design of parts, processes or tooling. Basics of numerical analysis methods, upon which the software are based, are also taught in the proposed course. With the assistance of these tools, students can visualize and better study the manufacturing processes. Issues such as cycle time, load and power requirements, material flow, solidification, thermal management, parts' defects and quality, or structural state of tooling and tool life can be well understood.

The authors discuss commonly used software tools, their methods of analysis, and their possible utilization in undergraduate and/or graduate level manufacturing course environments. Computer laboratory examples are presented to convey the importance of simulation in manufacturing process design. The study is completed after a specific look at die-casting process analysis through two different tools and methods, finite difference method (FDM) and geometric visualization, and their role in understanding the process.

Background

It is necessary to reduce manufacturing costs in today's market environment. Minimizing lead-time of the part, process and tooling design and minimizing the trial and error stage of manufacturing can help achieve this goal. It is also necessary to prolong the tooling service life and prevent catastrophic tool failures and down times since the tooling cost is one of the major contributors to the overall cost of the processes. The state of tooling also determines the outcome of the process, the product and its quality.

Utilizing manufacturing simulation tools which can simulate process power, load and speed requirements, work-piece material behavior, thermal or structural state of tooling during process, allows part, process and tool designers to improve their designs for better quality, less scrap and rework, more productive and less costly processes, and prolonged tooling life. It also gives them great power of flexibility in the manufacturing world of continuous improvement and dynamism. These simulation tools are basically means of optimizing part, process and tooling design.

Computer Aided Engineering (CAE) has long been used in analyses of engineering structures. Its use in manufacturing engineering has been growing in the last couple of decades. Major manufacturing companies have been utilizing engineering numerical analysis software in design of parts, processes, and tooling. These tools have become available to smaller companies with the advents in computers. Even though the cost of most software is still much greater than the cost of a powerful computer, software involvement is becoming more and more common in manufacturing design process. Increasing utilization of CAE in manufacturing process design resulted in the need for introducing these tools to engineering graduates. Schools have been raised up to the challenge, and various courses have been designed and offered. Cost of software is not an issue for academic institutions since many software companies have educational programs offering drastic price reductions to encourage schools to integrate their software with manufacturing curriculum.

This study presents a general manufacturing process course utilizing manufacturing process simulation tools as instructional aids. The objective of this course is to accomplish intelligent use of the software tools in learning design of parts, processes, or tooling. Basics of numerical analysis methods, upon which the software are based, are also taught in the proposed course. With the assistance of these tools, students can visualize and better study the manufacturing processes. Issues such as cycle time, load and power requirements, material flow, solidification, thermal management, parts' defects and quality or structural state of tooling and tool life can be well understood. For academic institutions, adding manufacturing equipment to their arsenal could be a very costly process. Although it could not replace a real world application, using a computer tool to study a variety of processes is a very effective approach in learning processes and manufacturing design process.

A Manufacturing Processes and Simulation Course

The proposed course" IE 5351 - Manufacturing Processes and Simulation" was designed when the authors were at Texas Tech University. It was to be taught in place of the graduate course titled "Advanced Manufacturing Processes" under the same course number. The goal was to enhance the experience of learning manufacturing processes by use of simulation tools. This course was inspired by a similar course, which has been taught for many years at Industrial & Systems Engineering Program at the Ohio State University. The Ohio State University course is "ISE 607 - Manufacturing Processes & Simulation". One of the authors, Arif Sirinterlikci was involved in the instruction of ISE 607 for a couple of years [1]. Even though ISE 607 is an undergraduate/graduate course, it mainly addresses to the graduate curriculum. Students at both schools acquire the material science and manufacturing process background before taking the courses mentioned above. They are not expected to have background in the numerical methods used in the software since the actual goal of both courses is to learn how to utilize simulation process tools to optimize part, process, and tooling design. The Ohio State course is based on 10-week quarters as compared with Texas Tech's 16 week semesters. The main difference between the two courses is that IE 5351 utilizes the software ABAQUS, a general FEM (Finite Element Method) code, as a simulation tool in place of ISE 607's DEFORM and SectionForm [], which are specific codes for metal forming and removal processes, and sheet forming respectively. The semester system and instruction lectures on the software allow students to get familiar with more complicated software. On the other side, it is easy to learn some specific software since they are only based on 2-D analysis or they have 2-D versions for specific type of problems such as plane strain problem. However, they are not as commonly utilized as a general FEM tool in the manufacturing world and most are still under development. 2-D models can also be created in general analysis tools.

IE 5351 cover both metallic and non-metallic processes in its limited scope. ABAQUS is used in the forming area, specifically in bulk and sheet forming laboratories. Casting processes are simulated through MAGMASOFT and CastView. Another code, PQ^2, is also used in understanding mold-filling process. Plastics forming and injection molding is covered with the assistance of C-MOLD. Figure.1, .2 and .3 show the sections of the syllabus for the proposed course. Figure 1 demonstrates the core information such as course description and objectives. Course topics and laboratory outline are presented in Figure.2, while Figure.3 gives a list of reference books in general manufacturing, metal forming, casting, and plastics processing areas. To evaluate students' learning 4 exams and 5 laboratory assignments are given. The exams are equally distributed throughout the term and non-cumulative. A final exam is not given. Laboratories are assigned during their topics' designated time periods as shown in Figure.2, once the instruction on the software and processes are completed. The laboratories are conducted by a group of students within 7 to 10 day periods, depending upon the requirements of the laboratory assignment and the number of students within each group. Students are given 3-D solid models of work-pieces and tooling to reduce lead-time of model preparation. However, they are required to create simpler (2-D) geometries. The individual student's effort and learning on each laboratory assignment is measured by including laboratory related questions in exams and by their participation during lectures and their interaction with faculty and teaching assistants.

Processes and Software Tools

Commonly used software tools, their methods of analysis, their possible use are presented here. Only the major software is mentioned in this section. Processes covered include metal forming, casting, plastics processing, and machining processes.

Analysis software can be divided into two groups as general and process specific. Commonly used general FEM (Finite Element Method) software tools such as ABAQUS or ANSYS can be utilized in thermal or fluid analysis of a casting process. Others like ProCAST or MAGMASOFT are specifically designed for casting processes. CAD/CAM software such as I-DEAS or PRO/E has also CAE ability and can be added to the mix, even though they are not as powerful the two groups. Another classification of analysis software can be based on the theory behind them. Most of the software is based on numerical analysis methods such as FEM or FDM (Finite Difference

Method). A few are based on simpler concepts, such as Section Analysis used in SECTIONFORM or a non-numerical method as in Geometric Visualization in CastView. Some other specific software, such as PICAT, focuses on equipment behavior used in plastics processing.

In this section, processes and their specific simulation software are mentioned. General analysis software tools can be used for a wide variety of processes, so they are not mentioned here. Bulk metal forming processes such as forging, extrusion, and drawing can be analyzed by DEFORM or ANTARES.

Sheet forming can be modeled through PAM-STAMP or DEFORM. MAGMASOFT, ProCAST or CastView can be used in understanding casting processes. PICAT (Polymer Industry Competance Assessment Tool) or MOLDFLOW (previously C-MOLD) can be used for a variety of plastics processes. DEFORM can also be utilized in machining analyzing processes.

The following section gives brief information on each tool and its capabilities. DEFORM, an FEM code, has a wide variety of modules responding to different needs and scales. DEFORM systems are based on a flexible automatic and optimum mesh generation criterion [2]. The meshing system works well with large deformation. The DEFORM systems also include equipment models to better reflect the real life hardware conditions. They can simulate corner unfill, load requirements, die pressures, deformed mesh structure, nodal velocities, and other field variables. They can also conduct thermal and coupled thermal-deformation analyses. The DEFORM systems include the following versions: DEFORM-3D for 3-D process analysis, DEFORM-2D for axisymmetric and plane strain process analysis on workstations and PCs, DEFORM-PC PRO for axisymmetric and plane strain process analysis on PCs, DEFORM-PC as a entry level 2-D PC based system. Non-PC modules run on UNIX platforms.

ANTARES is software used in forming processes like forging, extrusion or rolling. Like its competitors, it can model in 2D and 3D environments and deal with coupled thermal, elasto-plastic, elasto-viscoplastic, rigid-viscoplastic and workability modeling. It runs on both PC and UNIX environments [3].

PAM-STAMP 2G [4] has a capability of sharing data amongst its modules, improving its capabilities beyond a simple formability evaluation tool. It has 3 major modules: PAM-DIEMAKER for die design and optimization, PAM-QUICKSTAMP for rapid stamping simulation, PAM-AUTOSTAMP for accurate incremental stamping simulation for validation. PAM-DIEMAKER enables the user to design and optimize the binder surface and die addendum in a short time period. PAM-QUICKSTAMP utilizing elasto-plastic behavior, friction, blankholder pressure, drawbead and cutting pattern conducts a fast 3D evaluation. PAM-AUTOSTAMP has the ability to predict springback and to guide the modeler through the final validation of the forming process, tolerances and overall quality control. PAM-STAMP 2G is also capable of running on various platforms.

IE 5351 - MANUFACTURING PROCESSES AND SIMULATION

Fall 2001, Monday Wednesday Friday 10:00 – 10:50 am, IE 205 (Lectures)
Flexible Hours (Labs)
(3: 2: 3) Credits, Call # 14280

Instructor: Arif Sirinterlikci, Ph.D., Assistant Professor of Industrial Engineering

Office:	Room 201 L, (IE) Industrial Engineering Building
Phone:	742-3543
E-mail:	Arif.sirinterlikci@coe.ttu.edu
Office Hours:	Tuesday Thursday 4:30 – 5:30 pm

Course Description: Understanding manufacturing materials and processes through topics: metallurgical considerations, non-metallic materials and processes, casting and deformation processes, modeling and simulation for process and tooling design.

Prerequisites: Consent of instructor

Objectives: This course will provide a basic understanding of the mechanics of the manufacturing processes, their modeling and simulation. Greater emphasis will be placed on understanding the fundamentals of process modeling and less on computational methods. Details and governing theory behind the construction of software will not be provided. However, the intelligent use of software in the solution of manufacturing design issues will be the goal.

Text: Schey: Introduction to Manufacturing Processes, 3rd Edition, McGraw-Hill, 2000.

Laboratory: Accounts on the CAD/CAM and DEC Alpha Systems will be provided for each group of students. It is expected the following computer software will be used in this course: ABAQUS (bulk and sheet forming), MAGMASOFT, PQ^2 and CastView (casting), and C-MOLD (polymer forming). These programs will be used for process analysis and design. Problem solving techniques and intelligent interpretation of results will be emphasized.

The students will be formed into groups of 3 each. One report is expected from each group for each laboratory assignment.

Course Grading: 4 non-cumulative Exams 10% each (totaling 40%), 5 Labs 10% each (totaling 50%), and Participation 10%

Figure.1 Syllabus – Core information

COURSE OUTLINE

Topics	Week #
Introduction to Manufacturing Processes & Modeling	1 & 2
Mechanical Behavior of Materials/Deformation Processing Lectures on ABAQUS (Basics, FEM for Bulk Forming)	3 & 4
Modeling of Bulk Forming Processes (Forging, Extrusion, & Drawing)	5 & 6
First Exam	6
Modeling of Rolling & Sheet Forming Processes Lectures on ABAQUS (FEM for Sheet Forming)	7 - 9
Second Exam	9
Modeling of Casting Processes Lectures on MAGMASOFT, CastView & PQ^2	10 –13
Third Exam	13
Modeling of Polymer Processing & Injection Molding Lecture on C-MOLD	13 – 16
Fourth Exam	16

COMPUTER LABS

Lab 1	Simulation of Bulk Forming/Upsetting	ABAQUS
Lab 2	Simulation of Bulk Forming/Extrusion	ABAQUS
Lab 3	Simulation of Sheet Forming	ABAQUS
Lab 4	Simulation of Solidification/Casting	MAGMASOFT/ CastView/PQ^2
Lab 5	Simulation of Injection Molding	C-MOLD

Figure.2 Syllabus - Course outline and computer laboratory listing

REFERENCES

Manufacturing Processes:

- DeGarmo: Materials and Processes in Manufacturing, McMillan, 1987.
- El Wakil: Processes and Design for Manufacturing, 2nd Ed. ITP-PWS, 1988.
- Kalpakjian: Manufacturing Processes for Engineering Materials, 3rd Ed. Addison-Wesley, 1996.
- Tlusty: Manufacturing Processes & Equipment, Prentice Hall, 1999.

Metal Forming Processes

- Hosford and Caddell: Metal Forming – Mechanics and Metallurgy, Prentice Hall, 1983.
- Altan, Oh and Geigel: Metal Forming – Fundamentals and Applications, ASM International, 1983.
- Mielnik: Metalworking Science and Engineering, McGraw-Hill, 1991.

Casting Processes

- Flinn: Fundamentals of Metal Casting, Addison-Wesley, 1974.
- Heine et al: Principles of Metal Casting, McGraw-Hill, 1967.

Plastics Processing

- Dym: Injection Molds and Molding, Van Nostrand, 1987.
- Berins (Ed.): Plastics Engineering Handbook of the Society of Plastics Industry, 5th Ed. Van Nostrand Reinhold, 1991.

Figure.3 Syllabus - References for general manufacturing, metal forming, casting and plastics processing areas

MAGMASOFT is FDM based software with a modular structure [5]. It can run on both PC and UNIX environments. It simulates thermal and fluid-flow phenomena during casting processes. MAGMASOFT Standard simulates feeding, filling, solidification and cooling events. MAGMASteel, Iron, Thixo are add-on modules for analysis of steel and iron castings, and thixotropic materials respectively. MAGMAStress module deals with residual stresses and strains in castings in 3-D geometry. MAGMASOFT has also specific modules for low pressure and high pressure die casting processes and micro-structural analysis.

PROCAST is modular FEM software that can model a variety of casting processes such as sand, die, permanent mold and investment casting. Its base module consists of a pre and a postprocessor integrated with the thermal and solidification solver. Its' add on modules can be listed as: meshing, fluid, stress, radiation, microstructure, electromagnetic and inverse analysis modules [6].

CastView is qualitative or non-numerical analysis software. It is purely based on geometry. It can determine thin/thick sections of the castings, thin sections of dies, filling patterns and distances during cavity filling. It gives a jump start to the modeler allowing good understanding of the part and some process variables. Within a very short time period, various design alternatives may be eliminated through simple analysis. It can also run on both PC and UNIX platforms [7].

Moldflow Plastics Insight (MPI) is a modular system, which allows 3-D flow and thermal simulations using solid tetrahedral finite element mesh structure. It also allows, through its fusion module, analyses of thin-walled parts directly in CAD environment. MPI has numerous modules. Some of the modules are designated for specific processes like injection and compression molding, or reaction injection molding. MPI can analyze plastics flow, packing, mold cooling, shrinkage, and warpage issues [8].

PICAT (Polymer Industry Competance Assessment Tool) creates a virtual processing environment for plastics processing. Injection and blow molding, and extrusion processes can be studied through PICAT. Using the virtual environment, the program allows modeler to set process parameters to create a part within pre-set tolerances. Product and process faults can be identified and remedied with such a system even though it is not pure numerical analysis software like the other ones mentioned previously [9].

Laboratory Examples

Two laboratory examples are given in the appendices of this paper [1]. One is a forming exercise which requires DEFORM modeling, the other is a CastView exercise. Details of two casting process modeling tools are given in the next section [10].

Numerical and Geometric Analysis of Casting

Ideally the use of computer simulation allows the casters to reduce thermal and fluid flow defects and better design their tooling. Sometimes there is a need to analyze a casting design very quickly and choose from the acceptable design alternatives, before performing any computer simulations since the computer simulation requires complex calculations well as experience. Geometry based visualization techniques is one of the tools, which provides the casting design engineers a very quick and reliable analysis opportunity that can narrow down the number of simulation runs in the next step of analysis process.

In this section of the study, the capabilities of two analysis tools are discussed for analyzing two different casting processes: permanent molding and high pressure die casting process. First one is the easy-to-use purely geometry-based method and the other one is the more accurate and reliable tool based on the Finite Difference Method (FDM). The geometry-based tool, CastView can produce the analysis results in just a few minutes, whereas the finite difference method based software, MAGMASOFT gives the analysis results for the same model in a few hours. Sometimes, it may take longer, if the design is complex and multiple cycles are simulated. Despite the fact that, CastView uses only the part geometry to provide information about the part and process, its primary advantage is that it requires virtually no setup and provides results very quickly. So a quick evaluation of the alternative parting and gating options can be checked considering the balance in the fill pattern and characteristics of the fill path. However, the simulation in MAGMASOFT may take a longer time but results here are more accurate and reliable. Author, Shah Galib Habib used two different geometry models for two different casting methods shown in Figure.4 and .5 to analyze the capabilities of these two tools [10].

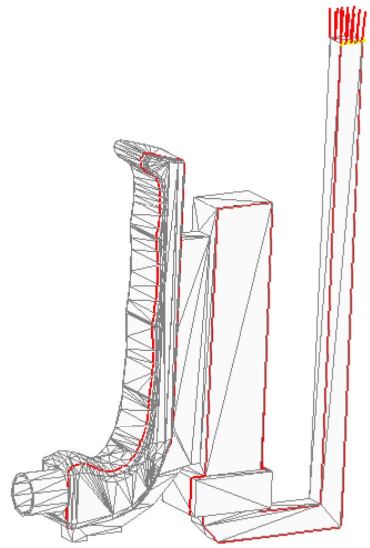

Figure.4 CastView model for permanent molding of an aluminum door handle [10]

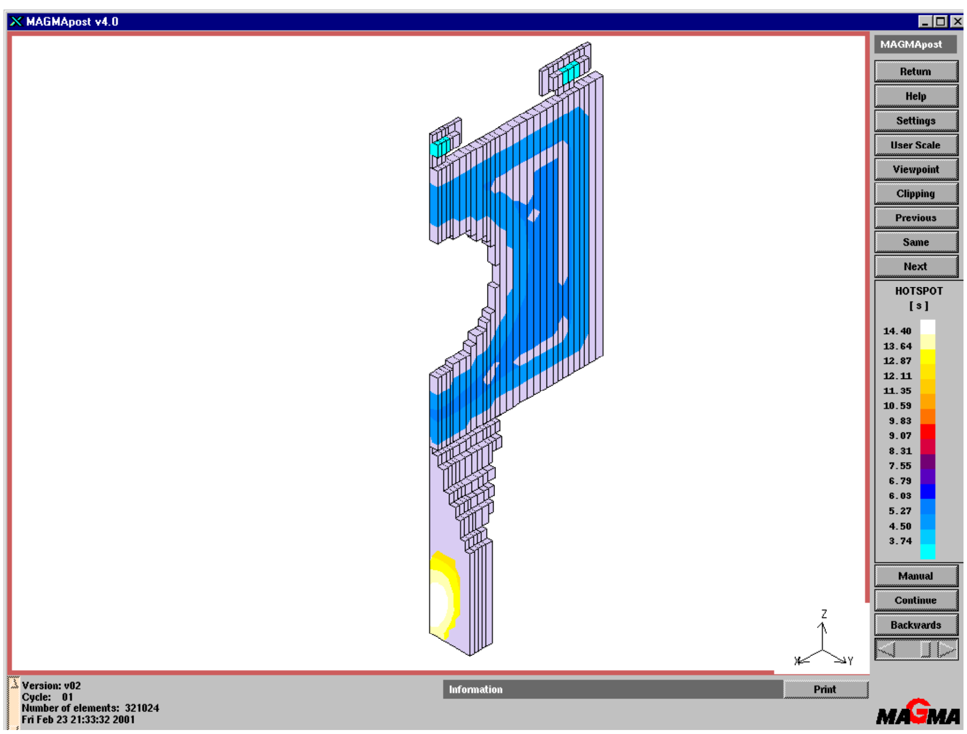

Figure.5 Hot spot analysis of a high-pressure die-casting through MAGMASOFT [10]

The following attempts have been made to summarize the comparisons between CastView, the geometry driven analysis tool and MAGMASOFT, the finite difference tool.

(1) Application areas

The fill pattern calculation based on the geometry based visualization technique is suitable for high-pressure die-casting. The principles used to develop the qualitative reasoning mechanisms

are purely based on the flow vectors defined at the gate and therefore the conditions are more suitable for high-pressure die-casting process. This is because the high velocity filling of the die cavity is a unique characteristic of the die-casting process. In contrast, the system based on finite difference technique uses pressure, temperature, inertia and gravity for the evaluation of the filling pattern and therefore is more accurate and reliable in analyzing the gravity die casting, low-pressure die-casting and other processes in addition to the high pressure die casting method.

(2) Ease of use

In order to run a numerical simulation, the designer needs to gather a great amount of information such as material data, thermo-physical data, information about the boundary conditions etc. Therefore, a good and sound knowledge of the designer is essential. For example, sometimes it is necessary to generate finer meshes at certain regions of the model in order to focus on that region, which requires special skills and knowledge. Also the designer must know the various design parameters involved in the process in order to provide proper input for the execution of the simulation. This creates huge difficulties for those who are relatively new with these processes. On the other hand, the geometry based technique presents a very easy modeling system, where the designer only has to specify the gate of the casting and it is also very easy to learn. Neither special techniques such as enmeshment, nor extensive software skills are necessary in geometric visualization.

(3) Geometry modeling capability

MAGMASOFT is a complete 3-D modeling system. Unlike CastView, it provides all the functionality required by the user to design a complete casting system. Furthermore, MAGMASOFT can integrate additional designs to the imported geometry models. The designer, of course, needs the required knowledge and expertise to use the preprocessing modeler of MAGMASOFT effectively. Both software accept data in STL (Stereolithography) format. CastView does require very little time in preparation of model geometry and has a new feature that checks the quality of STL structure.

(4) Result presentation

Graphical presentation of the results on the screen is a very essential feature for any kind of analysis package. Both MAGMASOFT and CastView produce 2-D and 3-D graphical presentation of the analysis results that directly show the critical areas in order to determine possible changes concerning geometry of castings or tooling, or process parameters. Furthermore, both of them provide animated display of the filling of the molten metal into the die cavity. However, MAGMASOFT can provide the shrinkage, filling, solidification, and fraction-solid results in the form of reports and plots as well.

(5) Result interpretation

Both software require interpretation of results. Care should be taken in interpreting the results. Those sections are significantly thinner than the rest of the parts may be harder to fill than shown by the visualization. The geometry based fill pattern analysis does not have any mechanism to estimate the effects of pressure, resistance to flow, or premature solidification effects that are likely to be important factors determining the fill of very thin sections. The reflections and direction changes can only be approximately accounted for using qualitative reasoning. In some instances, particularly with round obstructions, CastView may overestimate the amount of direction change. At times, other analysis types such as thick and/or thin section analysis could be used in conjunction with filling analysis to obtain better interpretation of results. Even though less interpretation is required in MAGMASOFT, it still requires interpreting certain data. In order to get the potential areas for gas porosity, we could look at the filling time results produced by MAGMASOFT. Also filling distance results are found from the filling pattern results.

(6) Accuracy of the analysis results

Properly designed numerical simulation of filling and solidification gives an accurate and reliable prediction regarding the overall casting process. Because, it considers design issues in very details such as material data, machine data, cooling line data, heat transfer coefficient values, even data like spraying time or delay time etc. However, the objective of the calculation is determined by the user. The filling of the cavity can be considered initially and the designer can follow this with a simulation of the cooling and solidification of the casting and the residual stresses in the part. On the contrary, CastView produces preliminary data which are obtained through geometric reasoning only.

(7) Time requirement

The essential steps to run a numerical simulation method such as meshing, prescribing boundary conditions require much knowledge and as well as modeling time. Furthermore numerical analysis usually begins with an initial cold condition. In order to get the results at a steady state, it requires several warm-up cycles to be completed. This costs a lot of CPU time and space. For instance, in the case of the door handle example as shown in Figure.4, it took about 2 hours to run the filling and solidification simulation for a total of 6 cycles. This is still a lot shorter than what an FEM based software may need. On the other hand, specifying the gate location and the geometry-based calculations done in CastView took altogether about less than 10 minutes, which makes it a very fast method for the casting process analysis. Furthermore, the geometry-based method makes all the evaluation at the steady state.

The main features of these two systems can be summarized in the table below. Following scale was used to evaluate each analysis type.

1 = Gives exact result
2 = Could be interpreted; the source is shown in the parenthesis.
3 = Does not provide information

Table.1 Comparison of MAGMASOFT and CastView [10]

	Analysis type	MAGMASOFT	CastView
1	Filling pattern	1	1
2	Filling distance	2 (From filling pattern)	1
3	Filling analysis by time	1	2 (from known gate velocity and filling distance)
4	Filling animation	1	1
5	Shrinkage-porosity	1	2 (Thick and thin section)
6	Gas-porosity	2 (From filling analysis by time or pattern)	2 (Filling pattern)
7	Feeding (Filling voids)	1	2 (Thin section)
8	Hot spot	1	2 (Thick section)
9	Solidification time	1	2 (Thick or thin section)
10	Fraction-solid	1	2 (Thick or thin section)
11	Temperature gradient analysis	1	2 (Thick and thin section)
12	Report presentation	1	3

Conclusions

Using simulation tools as instructional aids has been practiced more and more in graduate study environments since students have a better understanding of processes and analysis methods through longer years of study or practical experience. However, experience with ISE 607 has shown that qualified undergraduate students, especially those with a goal of continuing on to graduate study may reach to a very high level in learning of processes and their analysis.

At undergraduate level, basics of such methods as FEM, FDM, and geometric visualization can be taught alongside basic CAE software. However, it makes more sense if theory behind CAE is taught at a higher level. Such simple methods like geometric visualization or PQ^2 could be used in undergraduate level manufacturing courses in better learning of processes such as casting.

A good approach in utilizing process simulation tools as instructional aids, will be a course on a specific process such as bulk forming with help of ABAQUS or DEFORM to focus on a narrow area rather than dealing with a variety of processes. More theory behind the analysis methods may also be covered in such a class. On the other hand, better understanding of the big picture in modeling basic processing methods such as forming, casting of metallic materials, or plastics processing can be obtained with a course such as IE 5351 or ISE 607. In a general manufacturing process simulation course, the use of multiple software is a drawback since students cannot learn multiple software as much as they can single software. This problem can be solved by using general FEM code such as ABAQUS or ANSYS to model wide variety of processes in place of process specific software such as DEFORM or MAGMASOFT. There are two drawbacks of not using process specific software, the specific software carries detailed databases of material properties and can create more detailed data of processes. However, accurate model building requires accurate material or process databases. No matter what type of tool is used, the modeler has to be sure that he or she is using accurate data.

Bibliography

[1] http://www-iwse.eng.ohio-state.edu/isecourses/ise607/
[2] http://www.deform.com
[3] http://www.ues-software.com/subhtm/products/antares.htm
[4] http://www.esi-group.com/products/pamstamp2G/index.php
[5] http://www.inas.ro/MAGMASOFT.htm
[6] http://www.ues-software.com/subhtm/products/procast.htm
[7] http://www.diecasting.org/PUBLICATIONS/316-cd.htm
[8] http://www.moldflow.com/products/MPI/index.htm
[9] http://www.aroutsis.com/simulate/index.htm
[10] Habib, S.G., Comparison of Geometric Visualization and Finite Difference Method in Analyzing Casting Processes, Master's Thesis, Texas Tech University, 2001.

Appendix 1- Laboratory Example 1 - Forging [1]

ISE 607 - Manufacturing Processes & Simulation

Winter'02 Lab.#1 - Upsetting

Due: Tuesday, January 29

Background

The forging operation known as upsetting involves placing a solid cylindrical workpiece between two flat dies and reducing its height by compressing it. Cold upsetting is typically used to test the material behavior of the workpiece at large strains. Thus, it complements the classical tensile test that is limited to relatively small strains because of necking. At low temperatures, many metals exhibit strong work hardening behavior. Thus, the flow-stress relationship can be represented by a power law equation. Cold upsetting of cylindrical workpieces is conducted to obtain information about flow stress and forgeability levels for materials.

The ring test is commonly used in forging studies to measure the friction factor at the interface between the workpiece and the dies. It involves the compression of a ring shaped specimen between two flat dies. Material flow depends upon the value of the friction factor. The final shape of the specimen is determined by the friction conditions at the interfaces. As the height of the ring is reduced, the ring expands outward radially. If the friction at the interfaces is zero, both the inner and outer diameters of the ring expand as if it were a solid disk. With increasing friction, the inner diameter becomes smaller. For a particular reduction in height, there is a critical friction value at which the internal diameter increases from original if m is low and decreases if m is high. By measuring the change in the specimen's internal diameter, and using the curves shown in Figure.4.8 (see the appendix), which are obtained through theoretical and numerical (FEM) analyses, we can determine the coefficient of friction or friction factor. Each ring geometry has its own specific set of curves. The most common geometry has outer diameter to inner diameter to height proportions of the specimens 6:3:2. The actual size of the specimen usually is not relevant in these tests. Thus, once you know the percentage reductions in internal diameter and height, you can determine the coefficient of friction or friction factor from the appropriate chart.

Objective

The objective of this lab is to introduce the different upsetting processes and the process conditions to the students.

Laboratory Data

The lab is divided into two cases to simulate cold and hot upsetting process and cold ring tests.

Case 1: Upsetting (isothermal)

Case 1 involves cold and hot upsetting of cylinders between two flat rigid dies at different friction conditions (Each group is assigned to work with different material, and each person is assigned to different process temperature.).

Geometry:

Initial Radius for Workpiece:	1.0 in
Initial Height for Workpiece:	4.0 in
Mesh for Workpiece:	250 elements
Die Diameter:	10.0 in

Process Conditions:

Upper Die Speed:	1.0 in/s
Lower Die Speed:	0.0 in/s
Temperature:	please refer to the course webpage for different options
http://www-iwse.eng.ohio-state.edu/isecourses/ise607/	
Reduction in Height:	50%
Friction factor:	m=0.0 and 1.0 (no friction and sticking friction)
Number of steps:	100

Assignment

a) Hand in the following the plots: (for both cold and hot working)
- For both friction factors, a deformed mesh plot at maximum reduction.
- For both friction factors, an effective strain contour plot at maximum reduction.
- A load-stroke curve for both friction factors.

b) Answer the following questions briefly.
- What influence does the friction factor have on the deformed geometry?
- Where does the maximum effective strain occur? Compare the effective strain contour plots for both friction factors.
- How is the load-stroke curve affected by the friction factor. Why does the curve not start at the origin? (Hint: Think about how DEFORM models the material behavior.)
- If the diameter of the workpiece was an inch, what major problem can be expected during upsetting? Discuss.
- Compare the results within the group for different working conditions, and discuss the influence of working temperature on the load-stroke curve.

Case 2. Simulation of a Ring Test (Cold only)

The objective of this section is to simulate the compression of a ring using flat, rigid dies under isothermal conditions. The workpiece material is the same as Case 1. (use the same material as case 1)

Geometry:

Initial Outer Diameter for Workpiece:	6.0 in
Initial Inner Diameter for Workpiece:	3.0 in
Initial Height for Workpiece:	2.0 in
Mesh for Workpiece:	250 elements
Die Diameter:	10 in

Process Conditions:

Upper Die Speed:	1.0 in/s
Lower Die Speed:	0.0 in/s
Stroke:	1.0 in
Temperature:	70 F
Friction Factor:	m=0.0, 0.1, 0.3 and 1.0
Number of simulation steps:	100

Assignment:

a) Enclose the following plots with your report:
- For all four cases a deformed mesh plot at maximum reduction.
- For the first and fourth case, a plot of effective strain contours.
- For all four cases, a load-stroke curve obtained by FEM.
- Using the data from results of DEFORM analyses of 10,20,30,40 & 50% reductions in height, obtain a curve of % reduction in internal diameter versus the % reduction in height for all cases. (Hint: Use the second graph in Figure 4.8)

b) Answer the following questions briefly.
- What effect does friction factor m have on the final shape of the ring and on the value of the final internal diameter?
- What effect does friction factor m have on the effective strain at the inner diameter and mid height area?
- For the first case, theoretically predict the effective strain at maximum reduction.
- For the fourth case, check if you have zones of low effective strain. Can you explain the formation of these zones?

Appendix 2 - Laboratory Example 2 – Casting [1]

ISE 607 Lab #6

Die Casting Simulation Using CastView

Introduction

There are a lot of variables to be considered in the die casting process. For example, the variables of importance are melt temperature, dissolved gas content, die temperature and its distribution, plunger velocity and its variation during the stroke, chamber pressure, cavity pressure, and gas composition, just to name a few.

In this lab, you are asked to use CastView software to simulate the die casting process. You will be given the part geometry, so you don't have to generate your own.

Requirement

You will need to answer the following questions.

1. Where are the first and the last places that you would expect to see the solidification taking place? How can you improve the process condition (as long as the part geometry is not changed) so that the difference of solidification time can be minimized?

2. If we were to use casting instead of die-casting, where would you expect to put the riser? Why?

3. Please determine the gate location so that the whole parties filled at approximately same time. Also, try to determine the optimal number of gates.

4. Why would you need vent(s) in your die?

5. Using the optimal gate location you get in question 4, give information as to where to set up your vent(s).

The report is due on **Monday, March 11**.

Biographical Information:

ARIF SIRINTERLIKCI received his Ph.D. from Industrial and Systems Engineering Program in 2000 from the Ohio State University. He holds M.S. and B.S. in Mechanical Engineering from Istanbul Technical University in Turkey. He has been a faculty member at Ohio Northern University for the past year and was a faculty member at Texas Tech University for two years. He is a member of ASEE, NAIT, SME, Alpha Pi Mu and Epsilon Pi Tau.

SHAH GALIB HABIB received his M.S. from the Department of Industrial Engineering at Texas Tech University in 2001. He holds B.S. and M.S. degrees from Bangladesh and Australia. He has been employed by Compaq (now Hewlett-Packard Company) in Houston, Texas since his graduation from Texas Tech University.