Integrating Product Optimization and Manufacturability in Graduate Design Course

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Abstract

As CAD/FEA/CAM software tools are becoming increasingly user friendly and seamlessly integrated, it became feasible to use a number of them simultaneously in a senior/graduate level design course in order to provide students with opportunity to experience all aspects of product design cycle, from concept design, product optimization, to manufacturability. In the past, teaching a hands-on laboratory course on design optimization for functionality and manufacturability was virtually impossible because more powerful computer codes were very complicated and it was not practical to incorporate them in a single one semester course. However, standardization of commands and file storing formats resulted in seamless data transfer from one software package to another; thus, allowing integration of all facets of design optimization for product manufacturability in a single lab oriented design course.

This paper describes the experience with metalcasting design optimization course which focuses on design of cast parts according to its functional requirements (using IronCAD), while optimizing its shape with respect to its structural integrity (using COSMOS/M and DesignSTAR), and making certain that the part can be manufactured (cast) without defects (MagmaSoft). Throughout the course students are required to make a number of design revisions in order to satisfy specified design requirements. At the end of the course, students have a chance to present and defend their design in front of the class and industry representatives.

I. Introduction

Design process is becoming increasingly more complex as new knowledge is acquired and new technologies developed. Designer is facing a challenging task of having to constantly keep current with new developments so that his/her designs can be more competitive. The fact that knowledge is doubling every several years makes this task very difficult. Designers must also branch into other areas relevant to their own in order to improve on product development time and increase probability of the initial product manufacturing success rate.

In the past, one engineering department would pass their solution to another and then onto manufacturing without thorough understanding of the requirements and limitations of the following design/manufacturing step. The whole process was fairly slow, trial and error solutions were common and manufacturability was not guaranteed the first time around. This has been rapidly changing with advances in computer technology and computational tools. Initially, engineering software packages were complex and they were useful only to a particular group of engineers. However, these tools are becoming increasingly user-friendly and generate results that can be seamlessly integrated into other software packages for further analysis. As a result, it is becoming important that CAE software is used in its entirety so that the final design solution can take full advantage of the available materials and manufacturing processes.

Typical example of design integration is in design of metalcasting components. Metalcasting components are used in almost every aspect of everyday life from automobiles[1] to spacecraft[2]. They are used as structural components as well as non-structural ones. They are manufactured in millions (e.g. engine blocks) or as a one-of-a-kind part (e.g. art sculptures). Metalcastings can be as small as fraction of an ounce or can weigh hundreds of tons. The major advantage of metalcastings is that the metal can be placed in the optimum location for maximum strength, wear resistance or for some other property[3]. As a result very complex parts can be made to near-net shape, and that advantage has been supplemented with recent development of stronger and lighter cast alloys (e.g. austempered ductile iron and magnesium alloys).

Design and manufacture of metalcasting components typically starts with designer drawing a cast component, then structural engineer would check its integrity, and verified design would then be passed to foundry for manufacturing. As a result of this open loop approach the final product is most likely not optimal with respect to its mechanical as well as to manufacturing characteristics. The reason is that typically each of these steps involves expertise particular to that area that is difficult to find in a single person. In the past it would require the need for large production or very demanding application to optimize the part for its performance and manufacturability. Namely, interaction between all three groups and several design/manufacturability iterations are required to derive suitable optimal solution that would take advantage of available materials and processes. Nowadays, with very powerful computers and very accurate computational tools it is relatively easy to encompass the entire process of metalcasting design into one person or into a smaller team that can ensure better solution in shorter period of time with higher probability of success in initial production. This fact has been recognized by several advanced thinking foundries that are considered to be at the forefront of the research and development in metalcasting area[4]. According to these top manufacturers of metalcasting components, the survivors in the metalcasting arena will be the full-service suppliers with state-of-the-science processes and components.

This trend has been supported and acknowledged in the academia as well through integration of design and manufacturing into a single course. In the Mechanical Engineering Technology Department, Purdue University, a new graduate level course “Optimization of Metalcasting Design” was developed so that students can take full advantage of this manufacturing process and available materials and that their designs can be successfully manufactured the first time around.

II. Course Description

“Optimization of Metalcasting Design” is a graduate level 3 credit hour course with 2 lecture + 2 labs structure. The lecture section of the course can be subdivided into three areas: (a) overview of existing metalcasting processes, (b) physical phenomena in metalcasting, and (c) design issues involved in metalcasting design. Overview of metalcasting processes includes advantages and disadvantages of a number of metalcasting processes as well as their capabilities in terms of section thickness, surface roughness, mechanical properties etc. Physical phenomena include study of fluid dynamics, thermodynamics, solidification dynamics, casting accuracy etc. that are important in understanding the results of metalcasting process. Metalcasting design issues include design of gating and risering system, design for economical molding and coring, design of thin and non-uniform sections etc.

The lab section of the course is also subdivided into three areas: (a) computer aided design - CAD, (b) finite element analysis – FEA, (c) computer aided manufacturability analysis. The first part of the lab is used to teach students IronCAD software for 3D solid modeling. Although most of the students taking the course have prior knowledge of several CAD packages, this course has implemented IronCAD because of its ease of use and capability to produce 3D solid models that can be easily imported into subsequent modeling and analysis software without any additional modifications. This part of the lab instruction is limited to 3 lab periods that are enough to provide students with sufficient knowledge to produce simple 3D solid models and resulting production drawings. A typical example used as project assignment is shown in Fig. 1.

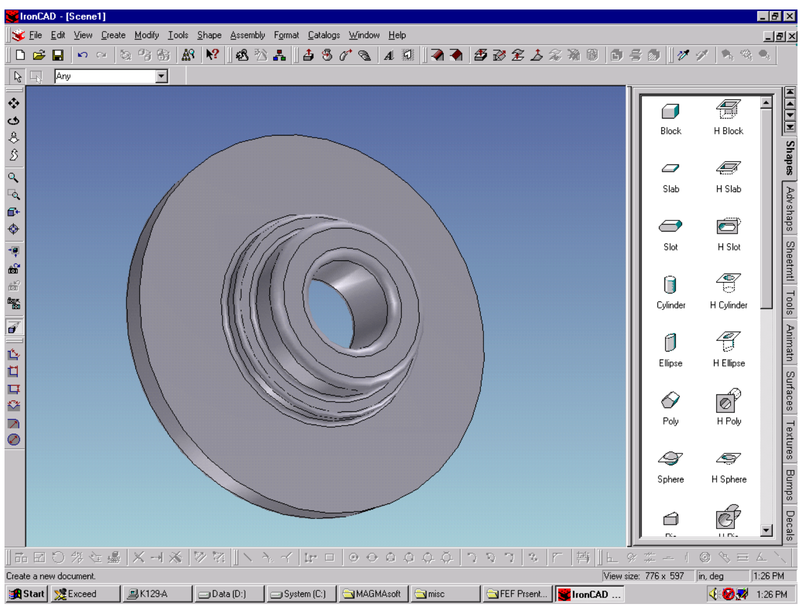
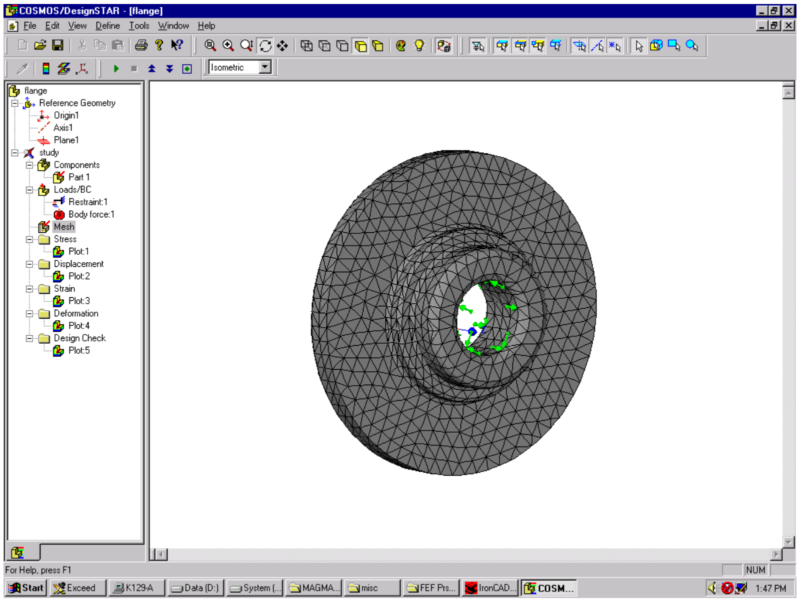


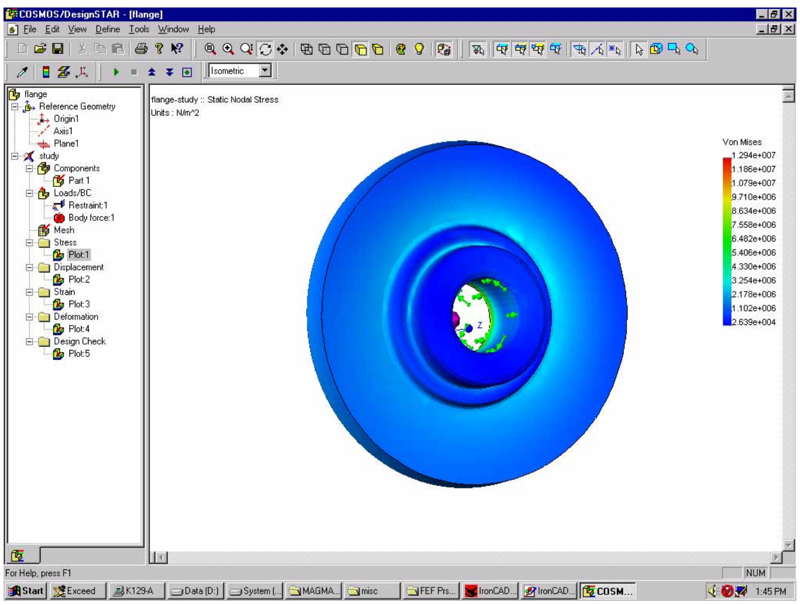
Figure 1. IronCAD solid model of a flange produced by Metal Technologies Inc.

During the second part of the lab, students use COSMOS/M - DesignSTAR module for linear stress analysis. 3D solid models generated in IronCAD are exported in the ACIS file format and subsequently imported into DesignSTAR. Once the part has been imported into DesignSTAR, user has to specify material of the part (i.e. material's mechanical properties), boundary conditions, and loading conditions. Meshing and processing part of the FEA are automatic and transparent to the user. These steps are simple and require minimal training time to master. The results of meshing and stress analysis, for the part shown in Fig. 1, are shown in Fig. 2(a) and

2(b). In this section of the lab, the emphasis is placed on underlying assumptions used in formulating FEA analysis, so that students can accurately use and interpret obtained results.



(a)



(b)

Figure 2. Finite element mesh and (b) stress distribution in the part subjected to body forces due to rotation of the flange.

Students have to determine realistic loads on the part as well as reasonable safety factor, and perform geometry optimization to satisfy safety factor. Since this process can take significant time to come up with optimal solution, the students are required to perform only one iteration of stress analysis, i.e. shape modification, so that they can proceed with other material required to gain a full perspective on the design optimization. Upon “successful” design of the part to meet structural criteria, the following step is to design gating and risering system that will provide good filling of the mold and solidification pattern in the casting. The basic requirement of the gating system (channels that connect mold cavity with outside world) is to deliver molten metal as fast as possible to the mold cavity while preventing turbulent flow, or at least surface turbulence. Also, the risering system must provide sufficient material to feed casting while it is solidifying, in order to prevent internal shrinkages in the casting. This task is accomplished by using available empirical data to estimate dimensions of the gating and risering system. This information is then translated into 3D solid design of the gating and risering system using IronCAD and modified part geometry that is “optimized” with respect to loading conditions. The result of this design is shown in Fig. 3. The solution is intended for manufacturing on vertically parted flaskless system that is characterized by high productivity. This figure shows another aspect of product/process optimization, i.e. maximum use of the available flask area by casting six parts at a time.

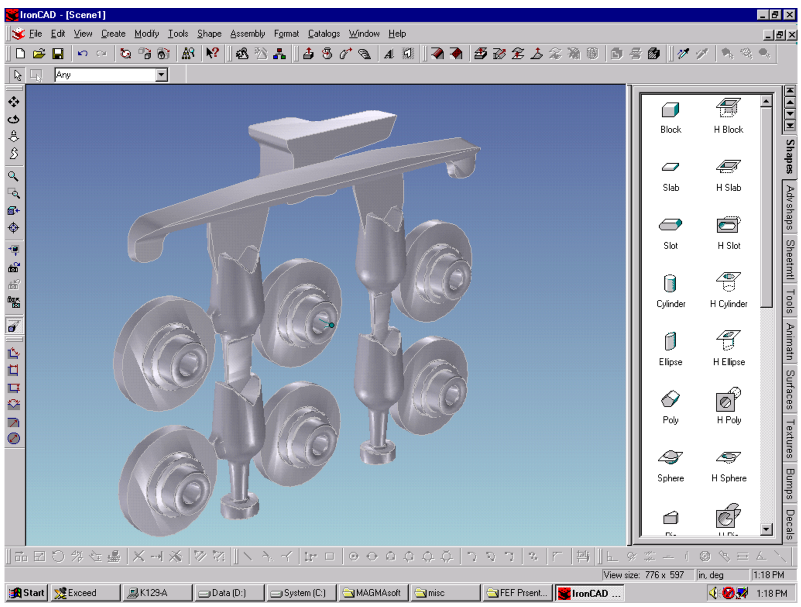
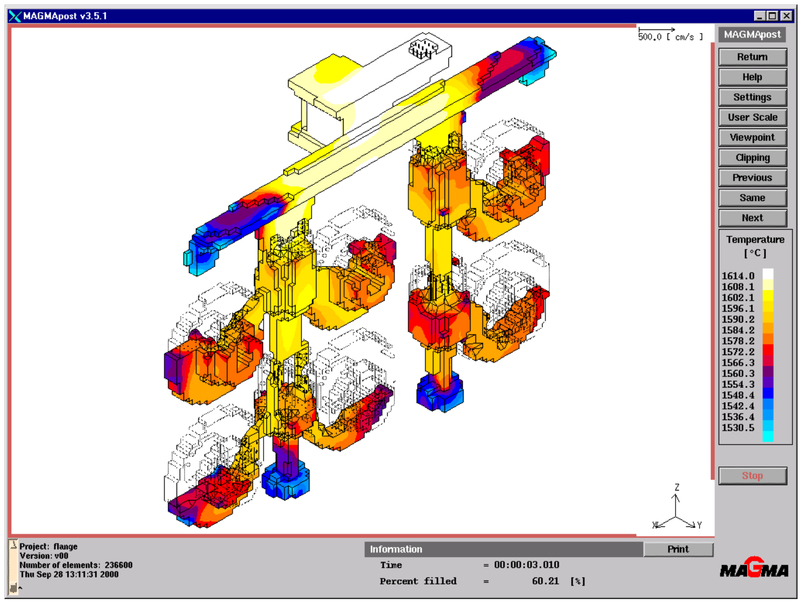


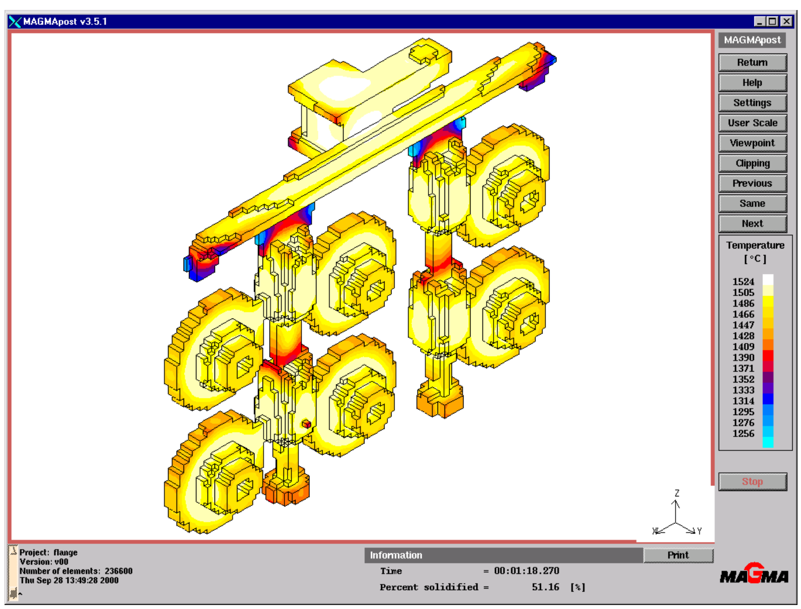
Figure 3. Gating and risering system for part shown in Figure 1.

In order to verify design of the gating and risering system the assembly (Fig. 3) is exported into STL file format and then imported into the MagmaSoft software. MagmaSoft is computational fluid dynamics (CFD) software that is modified to simulate casting related problems. The software also includes simulation of solidification, microstructure, and residual stress phenomena involved in the casting process. Using this software student can see the effect of their design on the casting process and if necessary modify gating and risering system to obtain desired process characteristics. In order to perform casting simulation, student must design mold around the casting and gating system, specify materials used for mold and casting, as well as specify number of other options related to meshing operation. The results of this simulation are shown in Figure 4(a) and 4(b). Figure 4(a) represents filling phase while Figure 4(b) represents solidification phase. Different colors on these figures represent temperature distribution;

however, user can request velocity field or some other variable to be displayed instead. Applying different analysis criteria embedded in the software, students can analyze if there is a chance that internal shrinkage can develop or if surface oxide film can be entrapped in the casting. If design results in potential problem, students are required to perform one iteration of this step in order to eliminate potential problems.



(a)



(b)

Figure 4. (a) Filling simulation, and (b) solidification simulation using MagmaSoft.

Finished part of one of the designs is shown in Figure 5. The part was cast in Metal Technologies, Inc., Milwaukee, Wisconsin. Engineers from Metal Technologies cooperated with students throughout the semester and provided them with useful information and guidance throughout the process.

Figure 5. Cast part of design shown in Fig. 1.

III. Conclusions

The process of metalcasting design optimization is quite involved, and due to its complexity and limited time available during one semester course, students are actually finding sub-optimum solution to a specified design problem while actually going through the steps of design optimization. The real world problems are most often non-trivial, quite involved problems that can take many months and significant computer simulation time to be solved, and the results are closely guarded industrial secrets. Hence, the goal of the course is not to find the optimum solution but rather to provide students with methodology and tools for successful optimization of metalcasting design that they will face in the real world, as well as to provide them with in-depth insight into design for manufacturing process that has numerous advantages over other joining, forming and machining processes.

The course is quite time consuming and requires significant amount of work, but students expressed overall satisfaction with the course. The general opinion was that the course provided them with very useful experience. The course has grown in popularity over time; it started with less then ten students and in one year increased the enrollment to twenty five students, which is actually the cap for the course. In addition, engineers from local industry also expressed interest in taking the course, which can be considered as another indicator of its success and practical application.

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Dr. Tomovic is an Associate Professor in the Mechanical Engineering Technology Department, Purdue University. He received his B.S. Degree in Mechanical Engineering from University of Belgrade in 1979, M.S. Degree in Mechanical Engineering from Massachusetts Institute of Technology in 1981, and Ph.D. Degree in Mechanical Engineering from University of Michigan, Ann Arbor in 1991. Dr. Tomovic teaches metalcasting, welding, and manufacturing courses. His research activities include manufacturing, metalcasting, welding, and design topics.