AC 2009-2519: MODELING, RAPID PROTOTYPING, CASTING, CNC PRODUCING, AND COMPARING THE MECHANICAL PROPERTIES

Richard Griffin, Texas A&M University, Qatar

Reza Rowshan, Texas A&M University, Qatar

Comparing the Mechanical Properties for an Al Alloy in the Cast and Wrought Condition using the Identical Solid Model

Dr. Richard B. Griffin and Dr. Reza Rowshan
Mechanical Engineering
Texas A&M University at Qatar
Doha, Qatar

Abstract

Junior level mechanical engineering students' have designed, rapid prototyped, cast, and tested a link in the laboratory portion of a materials and manufacturing course. A portion of this activity was described originally in a 2005 ASEE Conference paper. The activity has been used for several years in the laboratory portion of the course and it has been very successful. However, one question that comes to mind is May we compare cast mechanical properties with those of wrought properties for similar alloys. During lecture, comparisons of wrought and cast properties are frequently made, and it is shown that ratio of wrought to cast properties is frequently greater than one. To date, the direct comparison has not been done in this course. Using the student designed solid models, it is possible to directly make a rapid prototype part that can be used for the mold in a casting process, and that same model may be used in a CNC machine to make a similar part. Alloy 6061 was used to make the cast links and a section from the five inch diameter ingot will be used to make the CNC produced link. Mechanical properties will be measured using a universal testing machine. The results will be compared, and student interpretation of the results will be evaluated.

Introduction

In fall 2003, Texas A&M University at Qatar (TAMUQ) started an engineering program in Doha, Qatar under the auspices of Texas A&M University College Station and funded through the Qatar Foundation. The University has four engineering programs, which are Chemical, Electrical, Mechanical, and Petroleum Engineering. The initial group of engineers graduated in 2008. In steady state Texas A&M at Qatar is expected to have between 400 to 500 students enrolled in the four programs. Currently Mechanical Engineering has 67 students enrolled.

TAMUQ follows the mechanical engineering curriculum at the College Station campus. Currently, the program has nine faculty members, and plans are to hire several more within the next couple of years. Currently, our upper division classes have only been taught two or three times. The laboratory facilities were completed and available for use in fall 2007. The initial ABET review took place during fall 2008.

Within mechanical engineering, two required materials course are taught one is a three credit sophomore material science course and the second is a four credit junior materials and manufacturing course, which has been reported on before at ASEE meetings.[1,2,3] The course, MEEN 360, has three lectures per week and one three hour laboratory. The objective of this paper is to compare mechanical properties of cast versus wrought components for links that students' have designed, rapid prototyped, cast, and tested. The objective for the students was to maximize the ratio of the failure load to the mass of the link, which were made from aluminum alloy 6061.

Procedure

The activity extends over several weeks during the semester. Initially, the students design a link within the design space of 100 mm long, 5 to 7 mm thick and 30 mm wide. The design is done in solid works and the files are exported as STL files. Student's often use Cosmos, which is part of Solid Works to help them minimize the weight. Unfortunately, their method of operation is to remove material where blue shows up and add material where red appears. The laboratory is divided into three or four person groups. Each person designs a link, but the links for one group are all cast in the same flask and are attached to the same runner.

Students are in completion to develop a link that can carry the maximum load with the minimum mass (failure load divided by mass of link). A prize is given to the group with the highest ratio.

Once the link is designed and rapid prototyped, the students have time to prepare their links before casting. The links are used as the pattern in a green sand mold casting. The aluminum alloy was 6061. Examples of the rapid prototyped (RP) links on the pattern board are shown in Figure 1

Before testing, the students are given a second homework assignment where each of them has to predict where failure will occur, what the failure load will be and what it will cost to design, test, and manufacture the links. This activity requires them to use mechanics of materials formulations to solve for the failure loads.

Design

Figure 1 shows four of the designed links. One mistake that we made was to remind the students to put a draft angle on the edges of their designed link. This mistake will result in a problem later during the casting process.

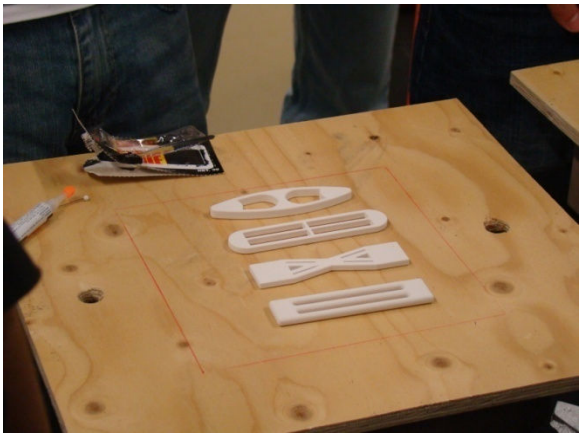

Figure 1. Rapid prototype patterns. This process uses a polymer for the part. After making the part, the students coat it with super glue to make the part tougher.

Cast

The casting process was probably the most fun for the students. Each group made a green sand mold. Examples of student preparing the flask are shown in Figure 2 and setting the flask on the insulating material in preparation for the casting process is shown in Figure 3. Two students in the class were selected to do the pouring, and as Figures 4 shows, we were very careful with regard to possible safety issues.

The problem with the lack of draft angles reared its ugly head during the removal of the patterns from the sand. Several stuck and more sand was removed from the mold than should have been because of the lack of draft angle. As shown in Figure 5, on the right hand side of the pattern board one of the castings only had two castings. The mold washed out where the sand had been pulled away from the pattern.

Additionally, as shown in Figure 1, some of the parts may have been too complicated for good casting considering the alloy that was used. Unfortunately, we realized that too late in the process.

Figure 2. Preparing the green sand mold.

Figure 3. Moving the completed mold to the pouring area.

Figure 4. Removing the ladle from the furnace.

Figure 5. Two of the three castings came out reasonably well, the third leaked out between the cope and the drag and as is shown on the right hand side of the pattern board, only two of the links of the three links were cast.

Test

Testing was done during the last class period of the fall semester. The results are shown in Table 1. The student names have been removed and replaced with numbers. The table is ranked on the basis of the highest ration of failure load to mass and Student 6 had the highest ratio and won the chocolate chip cookies. The masses of the links, shown in Table 1, varied by only 5 g, while in 2005 for similarly dimensioned links the masses varied from 27 to 90 g. As Table 1 illustrates, the comparison between theory and experiment was poor, only the three grayed specimens were within about 25% of the actual failure load.

Unfortunately, the CNC machine installation was not complete during the fall semester for machining the links. Currently, the parts are being readied to be machined, using the same STL files as the rapid prototyping machine. It is anticipated the results will be completed between now and the Annual meeting in Austin, Texas.

Conclusions

Students in an undergraduate material and manufacturing course designed, rapid prototyped, cast and tested a 6061 aluminum alloy link. The students were able to directly see the results of their design and the difficulties in translating an idea to a finished product.

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Table 1. Calculated and predicted data for 6061 cast aluminum links.

		Cast							Wrought		
		Dimension, mm			Prediction		Measured		Measured		
Student	Mass (g)	Length (mm)	Width (mm)	Thickness (mm)	Load at failure (N)	Location	Actual Failure Load (N)	Ratio P_{fail}/mass	Mass	Load	Ratio
6	28	110	25	5	2900	Corners	6983	249			
1	29				9770	Hole	6944	240			
3	29	105	25	5	13360	Hole	6969	240			
7	38				12100	Middle	8254	217			
8	30	120	25	7	8200	Hole	6113	203			
5	29	110	25	5	4200	Corners	4697	173			
2	26				6680	Radius	4091	157			
4	25	120	20	5	13750	Hole	3433	137			

[1] Griffin, Richard B., Terry S. Creasy "The Development of a Combined Materials/Manufacturing Processes Course at Texas A&M University,"ASEE Albuquerque, NM, June 2001.
[2] Griffin, Richard, Terry Creasy, and Jeremy Weinstein, "Laboratory Activity Using Rapid Prototyping and Casting," ASEE Montreal, Canada, June 2002.
[3] Griffin, Richard and Creasy, Terry, "Design, Rapid Prototype, Cast, and Test an Aluminum Link," National Educators Workshop Portion of ASEE Meeting, ASEE Portland, OR, June 2005.