AC 2005-226: DESIGN, RAPID PROTOTYPE, CAST, AND TEST AN ALUMINUM LINK

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Abstract

Integrated design, rapid prototyping, manufacturing processes, and testing has been accomplished in a junior materials and manufacturing class. Students are given a design space- 4 in x 4 in x ¼ in. Within that volume, they must design a link that may be rapid prototyped, cast, and then tested. The challenge of the project was to develop a link that held the highest load for the least weight. Students designed a link, made a rapid prototyped pattern, cast the component, prepared it for testing, and tested the link in a universal testing machine. The cast material was Al 356. The group that developed a link with the highest load to weight ratio took advantage of the fact the Al 356 alloy may be precipitation hardened.

Keywords

Design, rapid prototyping, casting, testing

Objective

The objective of this experiment is to allow students to design a component using solid modeling methods, develop a rapid prototype model, prepare a sand casting, and test the part in competition with other students.

Equipment and Materials

1. Solid modeling software (Solid Works® is what MEEN at TAMU has available.)
2. Rapid Prototyping Facility (A Z-Corporation unit is what MEEN at TAMU has available.)
3. Casting Facility (We have a green sand casting laboratory.)
4. Milling Machine available to prepare part for mechanical testing.
5. Mechanical testing machine.

Introduction

With the impetus from ABET, the faculty, and former students to include more design within the curriculum, the Materials Division within Mechanical Engineering was looking for ways to do this in a creative manner. Students many times see activities within separate classes as disconnected from other classes or even from a later activity within the same class. Over the past several years Mechanical Engineering at Texas A&M University has collected a variety of equipment that we have placed in an area that is called the Product Realization Laboratory.[1, 2] In an effort to satisfy all of the above customers, the Casting Design Challenge was developed and will be discussed in this paper.

Procedure

Early in the semester, the students receive the Casting Design Challenge. Figure 1 shows a portion of the Casting Design Challenge handout. Each Laboratory Group of four students could chose to make one design or they could each make a design for a total of four designs. One of the requirements was for the students to calculate the load carrying capacity of their link. They could do either hand calculations or use the Cosmos program found with Solid Works.® The links were tested at the end of the semester and the winning team received a prize during one of the last classroom lectures.

Casting Lab Design Challenge

February, 2004

Tension link

Your team will design a link for taking tensile load. You will cast four links. We will rank all teams according to the performance of their best link.

Figure of merit

Your link design will earn a performance number derived from this formula:

$$P = F / m$$

The performance P (lbs./lbs.) equals the maximum link load F, in lbs., divided by the link weight in lbs.

Your design challenge is to maximize P by keeping F as large as possible while reducing m. You must design an efficient link.

Procedure

- Review the allowed design space described below. Your design must fit within that space. The holes will accept pins that will load the link to failure.
- Do not cast the holes. Casting cannot produce the quality and placement required for tensile testing. The holes must appear in your drawing with an annotation that they be drilled after casting. Design the component with holes and suppress the holes before creating your STL file.
- Use Solid Works to create 1) a drawing of your link design for your casting report and 2) an STL file of the design for rapid prototyping of the blanks.

Design rules

You may apply any design method to maximize P under these conditions:

1. The design must be the work of your team and your team must design the link during this semester.
2. You may use stress concentration charts and 'rule of thumb' calculations.
3. You may use finite element analysis (COSMOS express or Algor or other packages)

if the package analyzes your Solid Works file.

4. You must document the steps taken, the software used, and the assumptions made in your report.
5. You must use the material properties listed in the appendix for your analysis.
6. You may not submit a link that exactly matches the design space[1].
7. Your design must be castable, e.g., it must have draft.

Design space

One flask will hold four links. Figure 1 shows four blanks positioned within the flask. There is a 1-inch gap between the blanks and the flask wall and between neighboring blanks. The sand in these gaps will insulate the flask from the hot aluminum.

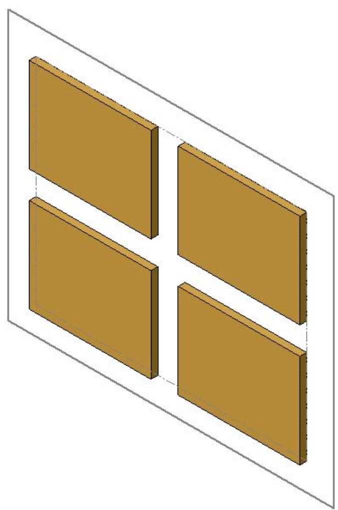

Figure 1. Four blanks fit within the flask. The gray line shows the location of the flask wall.

Figure 1. Introductory portion to the Casting Design Challenge.

Results

A variety of links were designed. Several appear in Figure 2. One of the surprises for the authors was the lack of calculation done before the link was cast. This was so even after repeated warnings to the students about making the calculations. For the most part, the calculations were made after the fact but before the mechanical testing. The results for predicted and actual failure loads are shown in Table 1 and 2.

[1] Really now! You could do better than that by guessing, which we do not allow.

Figure 2. Example of links in universal testing machine and four that have failed.

Discussion

The results were interesting. Alloy 356 is a heat treatable aluminum casting alloy that has good fluidity. The quality of the parts was fairly good with a surprising amount of detail and minimal clean-up required. Students had to drill the holes and remove some aluminum from the parting line of the casting.

The group (Group 2, Section 504) with the highest load to weight ratio is marked with gray in Table 1. They were the only group that heat treated their alloy. However, the predicted loads were not recorded. Group 2, Section 503 shown in Table 2 in gray showed their predicted and measured values. The values varied from 3 % low to 20 % high, which—all things considered—did not seem too bad.

Evaluation

Each semester, the students are asked to evaluate the laboratory activities by responding to the following two questions:

1. List three labs you felt were especially worthwhile and why?
2. List the three labs you felt could use improvement and what the improvement might be?

For fall 2004, the top three activities were machining (84 positive- 7 negative), link design, (51

Table 1. Mechanical Property data collected from the links for laboratory section 504.

Group	Dimensions				Measured	Failure	Weight	**Load/Weight**	Failure Location
	L	L2	Width	Thickness	Load	Stress	(lbs)		
1	4.186		0.754	0.284	2373.046	11151	0.0805	29490.6	Hole
	4.149		0.737	0.273	2343.75	11629	0.0772	30374.8	Hole
	4.176		1.27	0.275	2416.99	11785	0.0893	27070.1	Hole
	4.191		1.243	0.278	2666.02	13288	0.0893	29859.2	Hole
							1		
2	4.383		1.061	0.258	4160.156	24871	0.0947	43929.8	Hole
	4.383		1.02	0.245	2226.563	12268	0.0904	24632.8	Hole
	4.389		1.419	0.294	7221.68	20227	0.172	41996.3	Hole
	4.423		1.446	0.257	3852.539	10619	0.1698	22694.0	Hole
							1		
3	3.961		0.755	0.271	1787.1	14305	0.065	27478.8	Hole
	3.941		0.716	0.261	1479	22576	0.0628	23539.3	Hole
	3.979		0.715	0.26	1494.1	24663	0.0617	24204.3	Hole
	3.989		0.755	0.281	1611.1	26180	0.065	24772.5	Hole
							1		
4	4.411		1.915	0.404	4189.45		0.1929	21718.0	
	3.694		1.917	0.256	2578.13		0.1279	20162.6	
	4.033		0.565	0.26	1025.39		0.0694	14765.5	
	4.413		1.924	0.402	3090.82		0.1896	16302.2	

Table 2. Mechanical Property data collected from the links for laboratory section 503.

Group	Dimensions				Predicted	Failure	Measured	Failure	Weight	**Load/Weight**	Failure Location
	L	L2	Width	Thickness	Load	Stress	Load	Stress			
	in	in	in	in	Lb	ksi	Lb		Lb		
1	1.31	1.45	0.278	0.5	1551.5	(MPa)110	3457	7277.89	0.1355	**25512.92**	Hole
	1.31	1.31	0.265	0.5	3987.5	110.0	3940	29855.3	0.0969	**40660.47**	VERTICAL
	1.054	1.425	0.29	0.5	1551.56	110.0	4423	15251.7	0.13	**34023.08**	Hole
	1.01		0.245	0.5	1551.56	110.0	2563	10461.2	0.0925	**27708.11**	Hole
									1	**0.00**	
2	1.9	1.9	1.91	0.31	4808		4951.172	12541	0.1796	**27567.77**	Hole
	1.9	1.9	1.91	0.31	4808		4467.83	11316.5	0.20393	**21908.65**	Hole
	0.26	4.41	1.11	0.26	2163		1801.75	11360	0.07165	**25146.55**	Hole
	0.26	4.41	1.11	0.26	1744		1625	10245	0.07165	**22679.69**	Hole
									1		
3	4.43	0.94	1.346	0.272	4830	20989.8	2563	11141	0.111	**23090.09**	Hole
	4.412	0.835	1.353	0.261	4830	21694.9	2651.4	11907.5	0.106	**25013.21**	Hole
	4.415	0.895	1.359	0.271	4830	20748.4	3002.9	12899.8	0.111	**27053.15**	Hole
	4.419	0.954	1.376	0.273	4830	20196.7	2109.4	8820.4	0.117	**18029.06**	Hole
									1		
4		Area	0.159		2259.97	14213.6	1420.89	8936.42	0.06393	**22224.53**	Hole
			0.159		2259.97	14213.6	1582.03	9949.87	0.06393	**24744.97**	Hole
			0.239		3397.07	14213.7	2299.8	9622.59	0.09039	**25443.47**	Hole
			0.239		3397.07	14213.7	1860.35	7783.89	0.09039	**20581.69**	Hole

positive- 23 negative) and welding (40 positive-19 negative). There were 94 students in the class. From the students' viewpoint, the activity was worthwhile. However, we did not conduct a direct evaluation of the activity.

In terms of improvements, the authors' opinion is that the students still have difficulty connecting materials of mechanics information and the application of that information to the design process. Only a few of the groups think about it very carefully. We need to continue to develop the ability of students to apply material learned in one course to an activity in another course.

Implementation

Mechanical Engineering at Texas A&M University is fortunate to have the equipment available and a foundry for doing the above activity. It is possible to develop a similar activity where you might use machinable wax molds and then use a polymer as the casting material. Another possibility might be to use a CNC machine and either make a metal part or machine a mold and again use a polymer as the casting material.

Summary

We developed an experiment that required students to use solid works, develop a rapid prototype model, cast the part, and finally perform a mechanical property test.

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Authors

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