Designing, Rapid Prototyping, Casting, and Testing 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 approximately 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. Students used SolidWorks to design the link, and they were required to make a minimum of three calculations for failure and predict the failure load and location. 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.

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

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 may make one design or each student may make their own design for a total of four.

Casting lab design challenge: DESIGN AND ANALYSIS DUE:_______________; REPORT DUE 1 WEEK AFTER TENSILE TEST OF THE LINK.

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"Don't learn to do, but learn in doing."

Samuel Butler
"When I'm working on a problem, I never think about beauty. I think only how to solve the problem. But when I have finished, if the solution is not beautiful, I know it is wrong."

R. Buckminster Fuller

Tension link

You will design a link for taking tensile load and you will predict its failure load. You will cast four links. We will rank all teams according to the performance of their best link. The performance factor is the failure load divided by the mass of the 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[1]. You must design an efficient link in order to rank high in the class.

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.
- Predict the failure load document your analysis.
- Do not cast the holes. Casting cannot produce the quality and placement required for tensile testing. DO cast a depression that locates the centers of the holes. The holes must appear in your drawing with an annotation that specifies drilled holes. Design the component with holes and suppress the holes before creating your STL file.
- Use Solidworks 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.
- Your STL files and documented calculations are due on ________________. If you fail to submit a detailed analysis of the link we will reject your design.

Design rules

You must design your link under these conditions:

1. The design must be the work of your team and your team must design the link during this semester.
2. Your team may design and fabricate links in one of these scenarios:
    - Create one design, request/finish four RP patterns, and cast/test four copies. Calculate performance factor for each copy and evaluate fracture loads statistically in your report.
    - Create two designs, request/finish two RP patterns of each design, and cast/test four pieces (two of each design). Compare best figure of merit for each design.
    - Create four designs, request/finish one RP pattern of each design, and cast/test four pieces (one of each design).
3. You may use stress concentration charts and 'rule of thumb' calculations.
4. You may use finite element analysis (COSMOS express or Algor or other packages) if the package analyzes your Solidworks file.
5. Your report <u>must</u> document the steps taken, the software used, and the assumptions made.
6. You must use material properties from CES for your analysis.
7. You may not submit a link that exactly matches the design space[2].

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[1] Solidworks can hand you numbers for the volume and mass of your component.
[2] Really now! You could do better than that by guessing, which we do not allow.

8. Your design must be castable, e.g., it must have draft angle.

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.

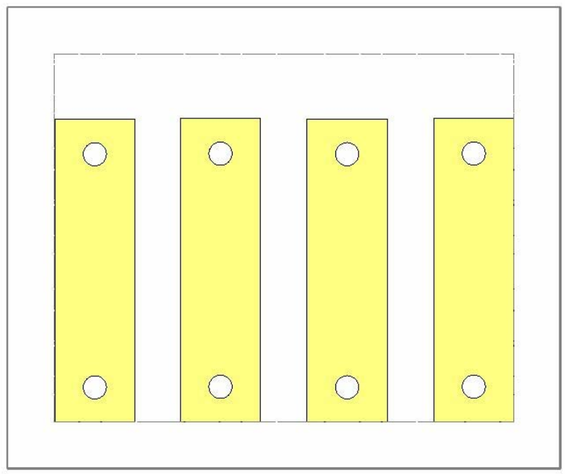

Figure 1. Four blanks fit within the flask. The gray line shows the location of the flask wall.

Figure 1. Introductory portion to the Casting Design Challenge.

One of the requirements is for the students to calculate the load carrying capacity of their link. They were to use the types of calculations that they learned in their mechanics of materials courses. Cosmos program found with Solid Works.® Our initial experience was interesting, because the students would use Cosmos by adding material where it shown blue and subtract material where the Cosmos results showed red. Thus, the requirement for having calculations included in the assignment. The links were tested at the end of the semester and the winning team received a prize during one of the last classroom lectures.

Results

A variety of links were designed. Several appear in Figure 2 along with the test fixture used. As mentioned above one of the surprises for the authors was the lack of calculations that were done before the link was cast. This was true 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.

Figure 2. Examples of several links and the test fixture.

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

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.

Conclusion

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. The students were very interested in the project and there was a great deal of interest in the results on the day of the testing.

Acknowledgement

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References

[1] Griffin, Richard, Terry Creasy, and Jeremy Weinstein, "Laboratory Activity Using Rapid Prototyping and Casting," ASEE Montreal, Canada, June 2002.

[2] 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.

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