AC 2010-1007: A STUDENT PROJECT EXAMINING ALTERNATIVE ASSESSMENT METHODS FOR STRUCTURAL COMPONENTS

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A Student Project Examining Alternative Assessment Methods for Structural Components

Abstract

Product development performance (cost and lead time) is of great importance in the current competitive market. Students today will enter a workplace where engineers have a wide array of design tools at their disposal to assess alternative designs and determine their fitness. Selection among alternative assessment methods requires that trade-offs be made among lead time, cost, and the reliability of the results obtained.

Assessing a given component using alternative assessment techniques allows for the analysis of the strengths and weaknesses of both analytical and physical prototyping methods. This process allows students to examine the limitation of analytical prototypes (or simulations) and alternative physical prototyping methods (rapid prototyping techniques) as well as their putative benefits (limited lead time and reduced cost).

This work details a project where students assessed the structural fitness (stress at various locations) of a simple component using simple calculations, finite element analyses (FEA), a fused deposition modeled prototype, and an aluminum prototype. The total time required to obtain information regarding structural fitness was tabulated for each method. The results for the other three methods were compared to those of the aluminum prototype (assumed to have the highest fidelity).

Introduction

Development is the process of creating technically acceptable solutions to meet customer needs. Today's students will enter a technologically driven world where the importance of development to the success (or even survival) of a firm is unquestioned. However, it is not enough that the product development process be effective, it must also be quick. Development lead time can affect the commercial and financial success of a product 1 2 3. Some companies even use time to market as a key product development metric 4. There is a potential conflict between trying to complete a development project quickly and producing a superior (or even acceptable) product. This conflict arises from the desire of technical professionals to engineer "perfect" products and the business reality of needing to deliver those products in an efficient and cost effective manner.

At most stages of the development process there are several alternative methods to determine the acceptability of a given design solution. These range from simple analytical prototypes (stress calculations or the use of hand books) to comprehensive physical prototypes (creation and testing of entire products) 5. New technologies in computer-aided design, manufacturing, and engineering allows for several aspects of a product to be analyzed virtually. The selection of assessment methods throughout the development process can have a significant effect on cost, lead times, and product and project success.

Conveying to students the importance of assessment method selection and the role that it can have on project and product success is of growing importance in engineering and engineering technology curricula. To evaluate a potential project that would allow students to examine alternative assessment methods a senior design project was commissioned. The goal of the senior design team was to test the feasibility of incorporating this type of project into other classes by defining and documenting their processes. This project (and associated documentation) comprised the requirements for the two-credit course. The methods and results of this senior design project are detailed in the following sections.

Background and Project Description

To examine the effect of alternative assessment methods on product and project risk, a senior design project was commissioned to evaluate the structural fitness of a simple component. The team consisted of three students that were in the final semester of a combined manufacturing and mechanical engineering technology program. These students were tasked with designing, performing finite element analyses (FEA), and manufacturing and testing two physical specimens. Three points of interest were selected to examine the mechanical behavior of the specimen in the presence of a load. The specimen, points of interest and loading configuration are shown in Figure 1. The span of the specimen is approximately 15cm. One prototype was manufactured using a fused deposition rapid prototyping process and the other from 6061 aluminum. The lower portion of the specimen was assumed constrained (as it would be in a fixture as shown in Figures 2 and 3). The students were asked to evaluate the specimen using four methods: simple stress calculations assuming only bending, finite element analyses, and the use of strain gages on the two physical prototypes. The students were asked to keep a diary of the time (person-hours) that they spent performing each of the tasks throughout the project.

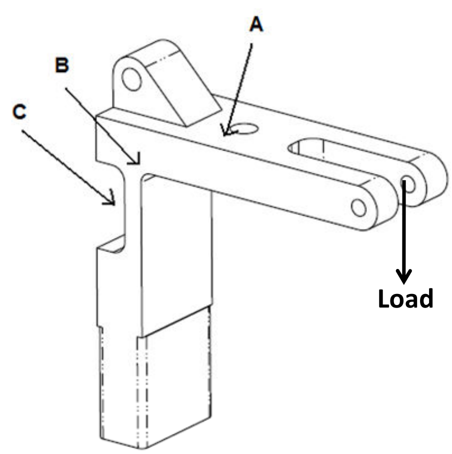

Figure 1. Diagram of specimen detailing points of interest.

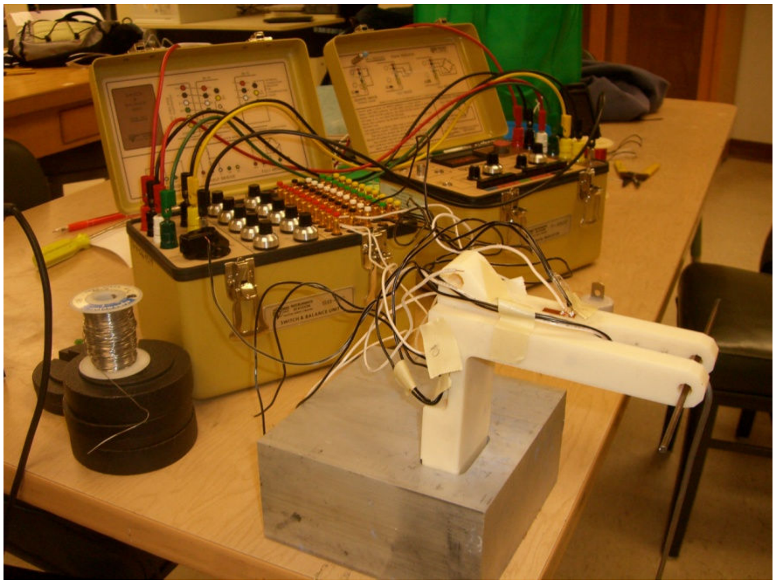

Figure 2. Diagram of rapid prototyped specimen in fixture.

Figure 3. Diagram of aluminum specimen in fixture.

The components were initially modeled in Pro|Engineer CAD software. Once the design for the component was finalized, the students began assessing its mechanical behavior. Given that the component was loading in simple bending, it was assumed that at the three locations of interest only the principal stress as a result of bending would be relevant. The analytical prototypes included simple stress calculations as well as finite element analyses. The simple stress calculation method consisted of performing bending stress calculations $\left(\sigma = \frac{My}{I}\right)$. These calculations took into account the stress concentration caused by the hole. Next, Pro|Mechanica (the integrated finite element program within Pro|Engineer) was used to perform the finite element analyses of the component assuming the previously mentioned loading conditions. The simulations were run and the predicted stresses at the locations of interest were tabulated.

Next the physical prototypes were fabricated and tested. The fused deposition rapid prototype was created on a STATASYS FDM 200mc using ABS*plus* (P430 ABS) material. The aluminum prototype was machined using a CNC mill (this required the generation of a numerical control program – g-code – that was created using FeatureCam). The material was cut to near net shape to minimize machining time. The prototypes were then instrumented with strain gages at the locations of interest and loaded in the aforementioned manner. The CEA-06-240UZ-120 strain gage and P-3500 portable strain indicator (used with half-bridge configuration) from Vishay Micro Measurement were used to measure uniaxial strain. The gages were attached with M-Bond 200 adhesive (also from Vishay) with soldered wire connections. The rapid prototyped component was tested using 295g, 590g, and 785g loads; the aluminum component was tested using 3kg, 5,kg, and 7kg loads. The loads were hung from the end of the specimen to produce a bending deformation (see Figures 2 and 3). Three samples were tabulated from the strain indicator at each location for each load. These strain results were then averaged and used along with the elastic moduli of the two materials (P430 ABS – 2.3GPa; 6061 aluminum – 70 GPa) to determine the stress at the points of interest (this assumed only linear elastic bending). The fused deposition prototype was used to mimic the geometry of the actual component and the relative elastic moduli were used to estimate what the stress would be in the actual component. While fused deposition parts may not be an appropriate analog for machined of molded components, their use does allow students to see the limits certain prototyping methods, thus enhancing the educational experience. The results of the structural analyses and their relationship with the person-hours required to obtain each of the results is detailed in the next section.

Results

For the purpose of this work, the aluminum prototype was considered the baseline for accurate stress results. All other assessment methods were compared to this baseline. The average deviation for the three loads at the various points of interest and the time required to complete the assessment are shown in Figure 4. All methods included an initial design time. All methods (with the exception of the simple calculations) also included CAD modeling time. The FEA assessment method also included time to set up, run the analyses, and analyze the results. The fused deposition prototype included time to import the CAD model into the prototyping software and the time required to clean the model. This method did not include prototype build time, as the machine did not require any interaction during the fabrication of the specimen. The completion time for the aluminum prototype included generating the CNC g-code for fabrication as well as the machining time required. Unlike the fused deposition process, it was deemed the CNC machining of the component required oversight and some interaction.

Table 1. Stress Results at Location A for Various Loads

Method	**Stress (MPa)**		
	3kg Load	5kg Load	7kg Load
Hand Calculation	0.68	1.14	1.59
FEA	0.78	1.20	1.68
Fused Deposition Prototype	0.11	0.23	0.30
Aluminum Prototype	0.61	1.07	1.56

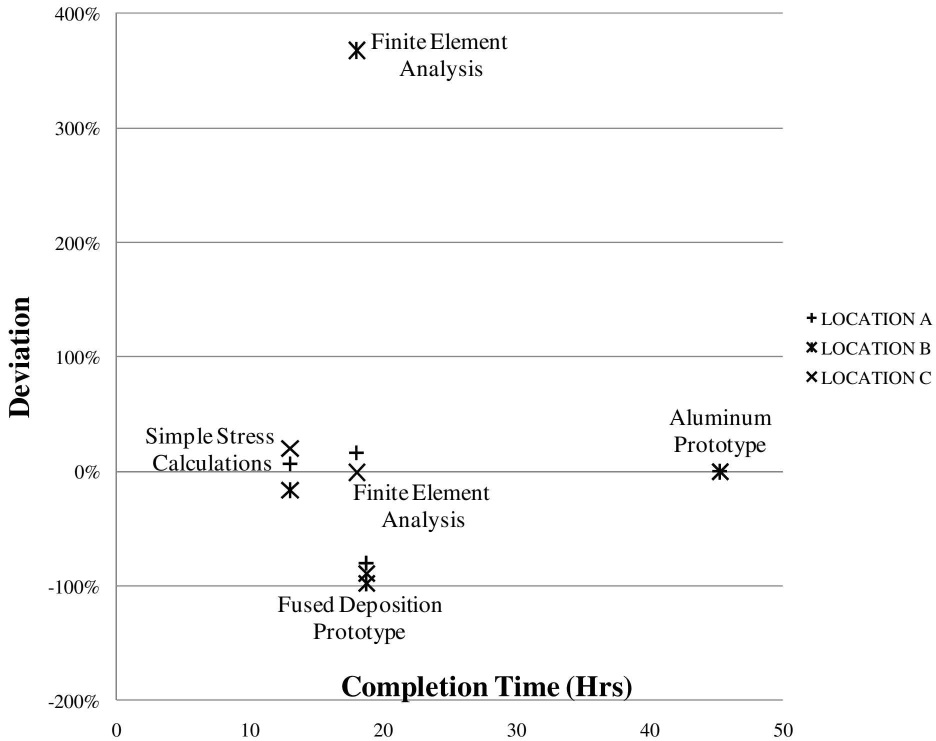

Figure 4. Relationship between completion time and deviation from aluminum prototype results.

The tabulated results for stress at location A (representative of other results) for the various loads are shown in Table 1. As seen in Figure 4 (and as would be expected), the simple stress calculations required the least time to complete. The results in the various locations were all within 20% of the reference point (the aluminum prototype). Only one of the data points (location B) predicted what would be considered a type II error (lower stress than the baseline). The FEA analyses required almost 50% more time to complete than the simple calculations. Two of the points were relatively close to the baseline values; the location C prediction showed type II error, but this was less than 1%. However, the predicted stress at location B was almost 400% greater than that of the aluminum prototype (this simulation was run numerous times with consistent results). This result was viewed as an anomaly (providing students with an example of why more than one testing method should be used). The fused deposition prototype required only a minimal amount of additional completion time (as compared to the finite element analyses). However, these results were significantly different than those of the baseline values. The average deviation for the three locations was almost 90%. This assessment method predicted significantly lower stress than that of the baseline (type II error). Finally, the aluminum prototype required almost 2.5 times as long to complete as the previous two methods and almost 3.5 times as long as the simple calculation method. Assuming that the aluminum prototype represented an accurate result, this accuracy came at a significant cost. It should be noted the type II error resulting from the simple calculation and FEA methods would be easily covered with a reasonable safety factor (e.g., 1.3).

Conclusions

A project exercise was presented that allowed students to comprehend the importance of assessment method selection and the role that it can have on project and product success. A simple structural component was assessed using four methods: simple calculations, FEA, a fused deposition rapid prototyping method, and an aluminum prototype. The time required to ascertain the desired stress information for various points was least for the simple calculation method and greatest for the aluminum prototype. The fused deposition rapid prototyping method produced results that deviated the most from the aluminum prototype (chosen as the reference point) and exhibited significant type II error (predicted lower stresses than the reference point). This exercise will allow students to better understand the consequences and benefits associated with alternative assessment methods that they will encounter as they enter the workforce.

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