Effects of Using Composite Materials in the Simulation of a Prothesis

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Abstract

This design project investigated the effects of weight and durability of a transtibial prothesis modeled on composite materials subjected to loads. The work focused on solid mechanics and modules of failure such as stress, strain, and fatigue. The work was achieved through simulation and tests on the SolidWorks software. Three models were designed and tested, involving some common and composite alternatives that were designated based on the geometry and usage of the part. Some of the materials considered were aluminum, titanium, and carbon fiber, among others. The results obtained were as expected because the composite alternatives exceeded on the tests, translating into lighter and more durable parts that complied with the purpose. The outcome of the project is relevant to understand better the applications and improvements that the composite materials can contribute to daily life activities.

Introduction

The main issue that prothesis wielders experience is that the equipment become heavy after prolonged time of usage. This project is focused on studying mechanical properties of common materials and composite materials, and how it can improve the weight of the parts and its durability. The prothesis that was studied was a transtibial prothesis, composed of a foot, a pylon, and a socket.

Background

The project mainly focusses on the principles of solid mechanics, specifically the stress and strains [1]. The stress focusses on the elastic and plastic behavior of the materials. The strain is the degree of deformation present on the part due to the loads applied. To achieve better results without having heavier parts, composites are the best option [2]. Composite materials are the binding of two or more types of materials (metals, ceramics, and polymers) to improve the properties. To understand better the prothesis equipment that was studied, previous works were reviewed for the individual parts. For the foot, the stress test was performed in which the composite alternatives prevailed on the tests [3]. For the socket, the work showed a lighter and more durable alternative when using the composites [4]. For the pylon, the alternatives gave better results when analyzed for the composites [5].

Problem

This project will focus on analyzing a 3D model of a prosthetic leg simulated on several material alternatives such as common and composite materials, subjected to static and cyclic loadings to establish an optimal alternative when designing and manufacturing equipment. This project will contribute to the knowledge of materials behavior in relation to its applications and mechanical properties on the medical equipments.

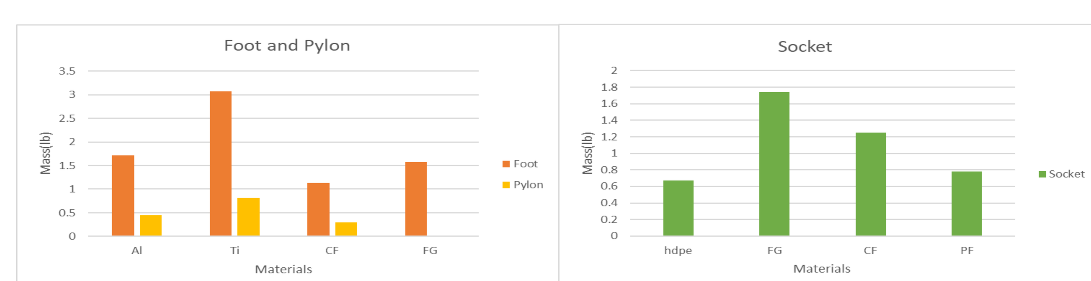
Methodology

The work was performed trough simulations with the SolidWorks software. The first phase involved the design of the parts of the transtibial prothesis, which included the foot, the pylon, and the socket. The parts were assigned materials according to its purpose and usage, involving the simulation of models on common material alloys and composite material alternatives. The common materials were Aluminum 6061T6, Titanium Ti-13V-11Cr, meanwhile the composite alternatives included Carbon Fiber AS4C 3k, Fiberglass and HDPE. The next phase involved the tests in which the stress, strain and displacement were analyzed due to applied forces to each individual part. The last phase involved the fatigue test that was performed on the assembly subjecting it to cyclic loads. After that the results were analyzed.

Results and Discussion

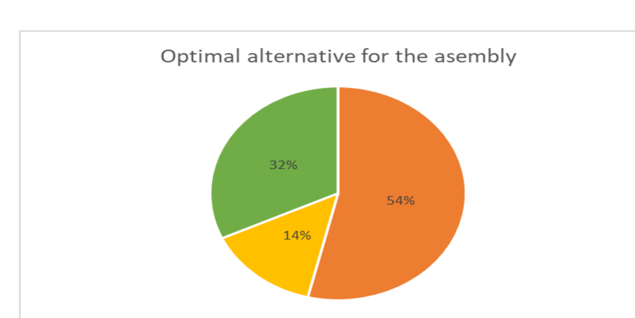
Based on the results obtained from the analysis and tests the following was found. In terms of mass as shown on the figure 1 the optimal alternative was a foot and pylon made of carbon fiber and a socket made of HDPE.

Figure 1. Mass of each component based on the material



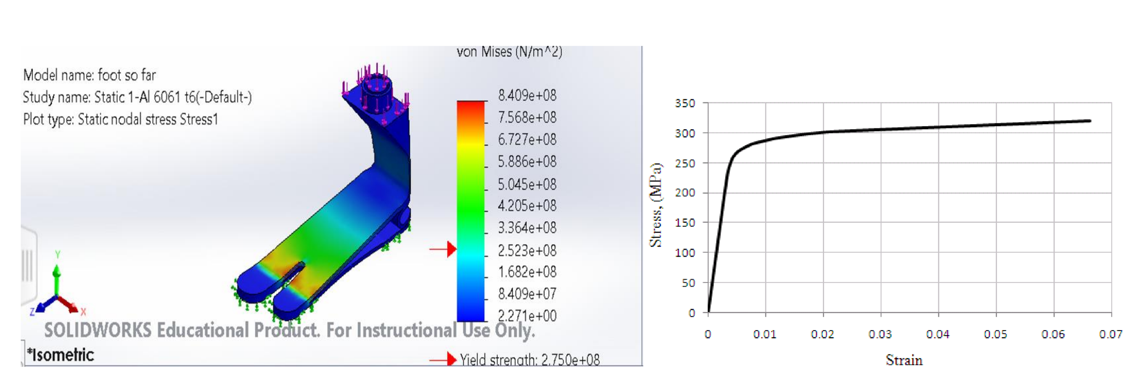
This combination is optimal because the total mass as shown on figure 2 was of 2.1lb, from which 54% of mass is on the foot, this helps in terms of stability. The 14% on the connecting rod and the remaining 32% on the socket. This complies with the objective to stablish lightweight alternative for the prothesis.

Figure 2. Mass distribution of the optimal assembly



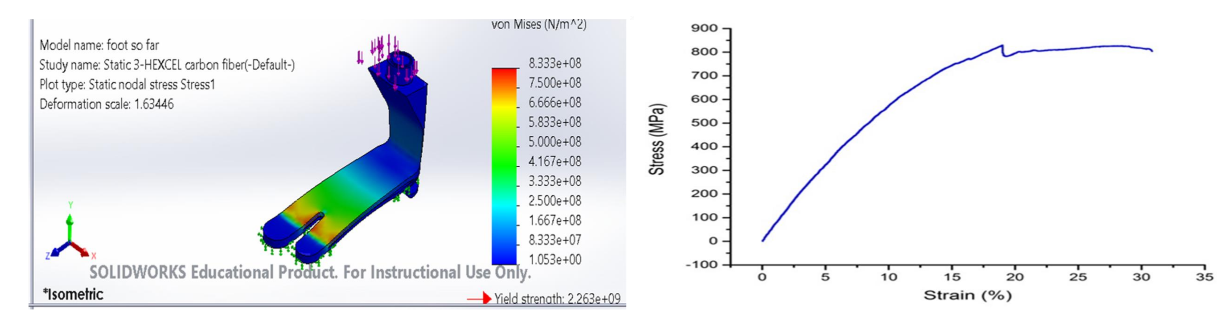
For the stress the test was performed on all the elements, for demonstration purpose, the foot analysis is presented for the aluminum and the carbon fiber. On figure 3 is presented the aluminum alternative for the foot and a typical stress vs strain curve. The model presented localized areas in which the stress overcame the yielding limit of 275MPa, therefore the part failed.

Figure 3. Stress results and typical curve of aluminum



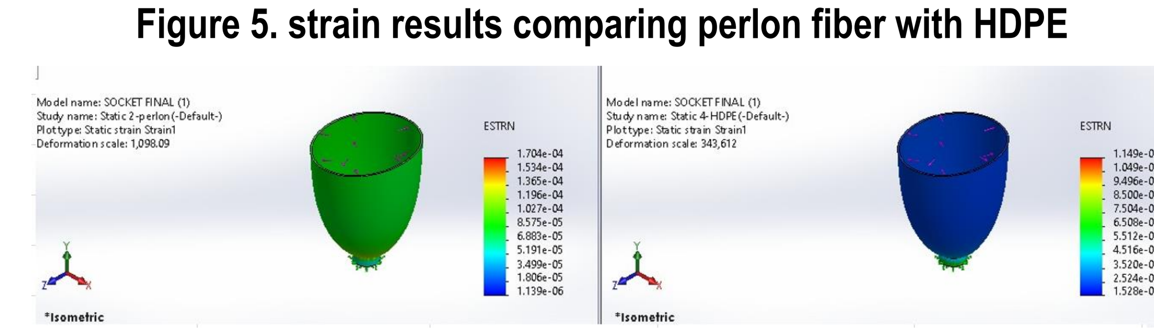
On a similar matter the figure 4 presents the results for the stress test and a typical curve of the stress vs strain curve for the model of carbon fiber. On this case the part didn't reach the elastic limit of 2.26GPa, therefore the part didn't suffer significant damage. The test was also performed on the titanium and fiberglass. The optimal option resulted on the carbon fiber. For the other components the test was performed and similarly the composite alternatives were the best alternative.

Figure 4. Stress results and typical curve for the carbon fiber



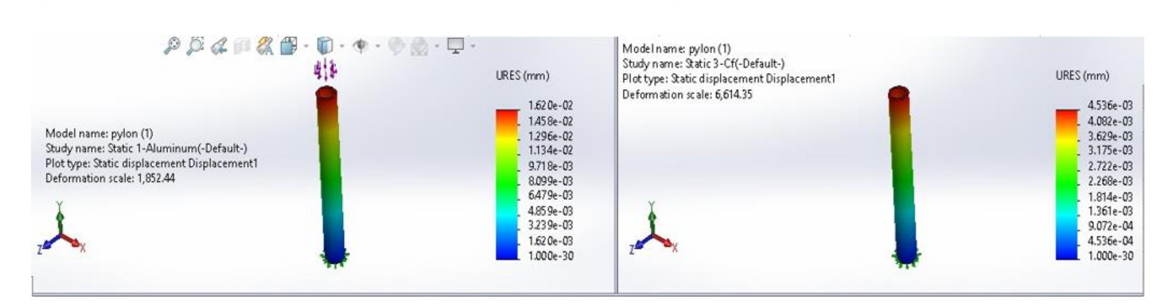
On the case of the strain, for demonstration purpose the socket was considered, comparing the results present on the figure 5 the average deformation strains were significantly low on the order 10^{-5}, which means it is considered small strain due to it being lower than 1. On the other components the test was performed resulting on the same values lower than 1.

Figure 5. strain results comparing perlon fiber with HDPE



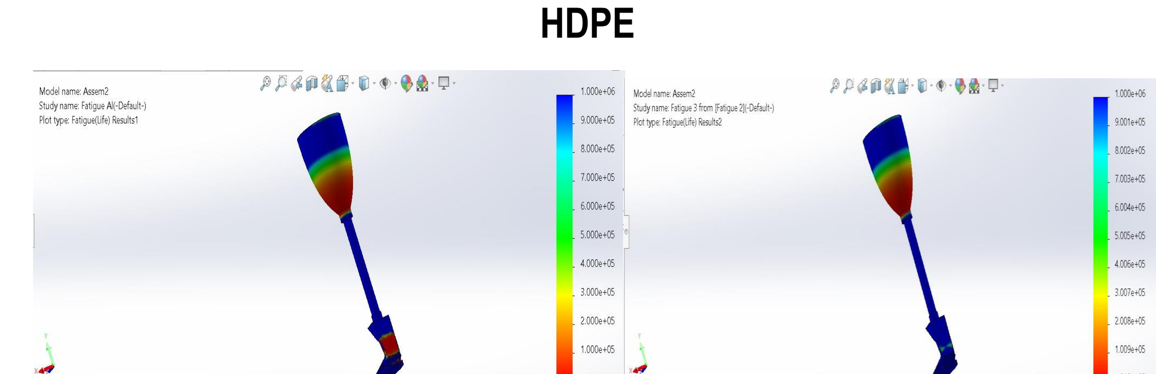
The displacement is represented on figure 6 which demonstrate how the part was moved when the load was applied. For this section, the pylon was considered showing that the displacement for the aluminum alternative was of 0.0081mm meanwhile the displacement for the carbon fiber was of 0.0023mm, therefore demonstrating that the composite alternative behaved better than the common alternatives

Figure 6. Displacement results comparing aluminum with carbon fiber



In terms of the fatigue test, it was performed on the assembly, for display purpose the Al-Al-HDPE and Cf-Cf-HDPE alternatives are shown. The aluminum assembly presented low cycle fatigue, which means the element has finite life. The carbon fiber alternative on the other hand reached infinite life as presented on the figure 7. Therefore, in terms of durability, the composite alternative excelled on the test.

Figure 7. Fatigue test results performed on Al-Al-HDPE and CF-CF-HDPE



Conclusions

Taking in consideration the results obtained, it can be said that the objectives of the project were met. It was proved that the composite material alternatives are lighter, as seen that the optimal option was the assembly simulated on carbon fiber and HDPE, giving a mass of 0.95 kg or 2.1 lb. In terms of stresses, the carbon fiber alternatives withstanded the loads without reaching elastic limits, as well as for the HDPE. Also, the strain deformation for the composites was very low giving results on the order of 10^{-5}, therefore considered small strains due to it being smaller than 1. The displacements for the composites was way lower than the ones for the common materials, this is associated to the strain deformations. In regard of the fatigue the composite alternatives reached high cycle fatigue and, on the pylon, infinite life was achieved opposed to common alternatives that failed at low cycles. In conclusion the composite materials alternatives excelled the tests and behaved better than the common materials options.

Future Work

Since the field of composite materials and its properties is an extensive study area some tasks for future work are, to expand the variety of composite alternatives that are studied, explore other geometries for the parts, and study the economic impact due to the materials.

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