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NUMERICAL SIMULATION OF A TRANSTIBIAL PROSTHESIS USING NATURAL FIBERS.

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Abstract. *This work presents a numerical model for structural evaluation of a "flex run" prosthesis type for people with transtibial amputation, comparing the viability of the use of composite materials using natural fiber (sisal). The human gait results from a complex interaction of muscular forces, joint movements and neural engine commands, thus the model was analyzed numerically through the Finite Element Method using the ANSYS software. This model take considers the geometry of the prosthesis, as well as the efforts that it suffers during running. The simulations were performed based on the prosthesis shape, verifying the loads applied in on the prosthesis during a real work situation and its response for different composites materials when under these loads. The results obtained for the use of those regional fibers showed to have an equivalent behavior when compared with the composites already used on the type of prosthesis. However, the use of each of these fibers leads to a changing in the prosthesis shape to reach a general mechanical behavior.*

Keywords: *Finite Element Method, Transtibial Prosthesis, Regional Fibers.*

1. INTRODUCTION

All people, including those with a disability has rights to attain quality of life, as well as the ability to move around from place to place independently. Currently, accessibility for people with some kind of disability is still very precarious.

The prostheses for transtibial amputees (below knee amputation) are designed for everyday use or for special applications such as the practice of sports. In sports, carbon fiber prostheses have been used usually because they present high performance. However, only a small proportion of amputees want to become a professional athlete, most just want to enjoy some exercise.

In the development of biomechanical products such as medical prostheses, one must always keep in mind the importance of simulation and modeling of such products as they allow the evaluation of the structural behavior of these prostheses when they replace the function of a body part. The modeling and simulation allow a detailed analysis and verification of the proposed component, and allows a possible optimization in prosthesis design to be manufactured.

The evaluation and development of these biomechanical products require structural analysis and modeling to assess their strength, particularly when subjected to external efforts. In that sense this article was developed to evaluate the numerical simulation of a transtibial prosthesis using composite with natural fibers, aiming to minimize costs and ensuring greater accessibility to the public. The finite element method (FEM) was selected for the numerical analysis as it currently present a development level that allows its general use in structural design, resulting in a valuable engineering tool in biomechanical applications.

Composite materials were used with a natural fiber (sisal), in which it was necessary to verify the mechanical properties of each composite through mechanical tests, and from these, simulate in ANSYS software using these estimated material properties. We analyzed the geometry adopted in the efforts by checking the distribution of stresses along the prosthesis.

1.1 Human gait analysis

The human gait is characterized by a rapid and complex sequence of events. It very important in the study and treatment of pathologies involving the human motion, however the article was limited to only analyze the movements of the feet and ankles. The biomechanics of the human gait involves the kinematics and kinetics of movement and also each person has its unique marching style varies according to several factors. The human gait cycle can be briefly divided into two parts: Stance and swing (figure 1) . Stance is the moment when the foot is in contact with the ground, and the swing corresponds to the moment when the foot leaves the ground.

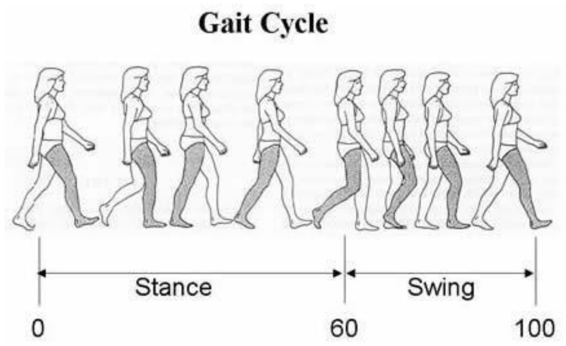

Figure 1 – Human gait cycle (ROSE and GAMBLE, 1994)

Regarding the human movement, it is necessary an analysis in two main approaches: kinematics and kinetic. The kinematics relates to the movement between rigid bodies and finds application in the analysis of the gait and other body movements, in which each member of the segment is considered a rigid body. Motion measurements are made with reference to the joint centers, thus these movements are the points of greatest cinematic significance. The displacement movement is a change of position in space and can be linear or angular. The gait kinetics is the description of human movement in terms of strength, and these forces can be internal and external. The internal forces include the result of muscle activity, tissue elasticity and internal friction, since the external forces are classified in relation to the ground reaction forces and external loads or resistance.

1.2 Prosthesis design

The prosthesis must be designed to withstand severe loading conditions during use. It is important to consider that amputees lose about 80% of energy required for normal gait cycle, so it is essential that the prosthesis presents some flexibility under bending stresses in order to store elastic potential energy, thereby contributing to the momentum of the corridor.

Composite materials were selected to construct this prosthesis. Composite materials have high specific mechanical properties and versatility for the production of different geometries and this fact makes these materials ideal for many applications. Such versatility is justified by lower manufacturing costs to and the possibility of different parts meets different mechanical properties. The material has to be flexible, to absorb shock and be resistant to endure the weight of the person, so that the prosthesis can properly meet user expectations in terms of performance. It should be light, since according to Nolan (2008) for the single leg amputee runner presents the same physical depletion of a non amputee runner, the mass of the prosthesis should be 1 to 1.5 kg.

The proposed geometrical model was developed in the form of a spring, with a curved surface in the area where it touches the ground (Figure 2). For a biological leg, it can be considered that during the race, the angle between the lower leg and the vertical axis is 0° when the foot touches the ground and 44° when the foot leaves (Buckley, 1999). In the design of the blade, composite of natural fibers were considered: a polystyrene composite reinforced with sisal fiber. The fiber content is equivalent of 30%. Given this configuration, a tensile strength of 45MPa and a Young's Modulus of 9998MPa are observed (Joseph et al., 1999).

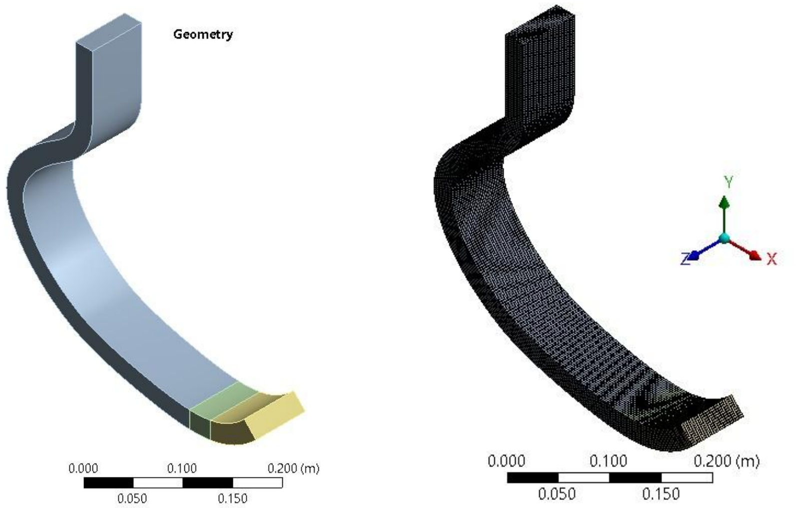

Figure 2 – Left: Prosthesis geometrical model. Right: Finite element Mesh

2. NUMERICAL SOLUTION AND FINITE ELEMENT MODEL

To evaluate the performance of the prosthesis, static structural analysis was performed by evaluating the rigidity and the failure criteria according to the fibers orientation when the component is subjected to efforts.

Table 1. Mechanical properties of fibers sisal

Tensile Strength (MPa)	**Elongation (%)**	**Toughness (MN m-2)**
580	4.3	1250

Fonte: Adapted Pavithran et al., 1987.

The material selected was sisal fiber with data given by table 1 (Joseph *et al.*, 1999). In present work, we applied a constant force representing the floor contact in the lower part of prosthesis and verify if the von Mises stress is below the maximum load supported by this material. The contact conditions with the floor considers a vertical force to support the main load and a friction force in the lowest area of domain. The value of the applied force obtained in Buckley (1999) study on human gait took into account the weight of a person of 60 kg. The direction and magnitude of the force applied changes along a walk. The vertical force has value of 600N and horizontal force, 120N (figure 3). This should represent the loads when the prosthesis touches the ground (case A). To represent the moment when it leaves the ground, the main and friction forces were rotated by an angle of 44°, resulting in a horizontal load of 382N and a vertical one of 478N (case B). Solid quadratic elements were used to discretize the volume domains corresponding to the prosthesis. The resulting mesh has 337707 nodes and 75880 elements (figure 2). The top area (representing the connectivity with body support) was considered as a fixed support. The movement will be represented by changing main and friction forces.

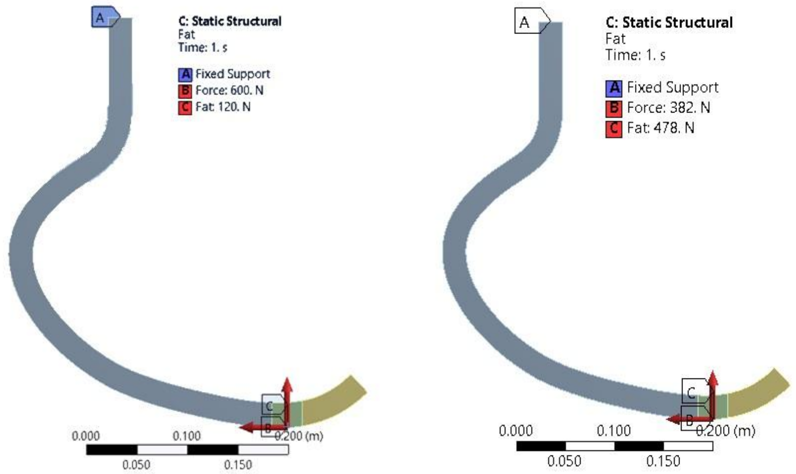

Figure 3 – Loads applied in finite element model. Left: Case A. Right: Case B.

3. RESULTS AND DISCUSSION

The results obtained for the two loads cases are shown in figure 4. As can be seen, the magnitude order of maximum stress is about the same (25MPa), but a change in its position is observed. In first case the main stress is due to bending in middle of spring. In case B, the main stress is also due to bending, but in the contact region of fixed boundary of prostheses. In any case, the maximum stress is below the tensile strength of the composite material.

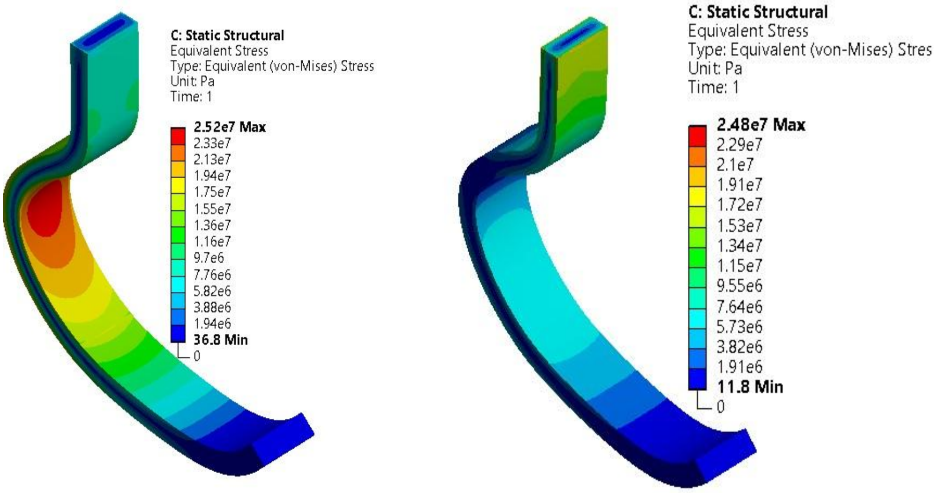

Figure 4 – Equivalent Stress. Left: Case A. Right: Case B.

Figure 5 shows the deformed shape of prosthesis in the two cases analyzed. This represents a very useful result as this deformation interacts in the gait kinematics.

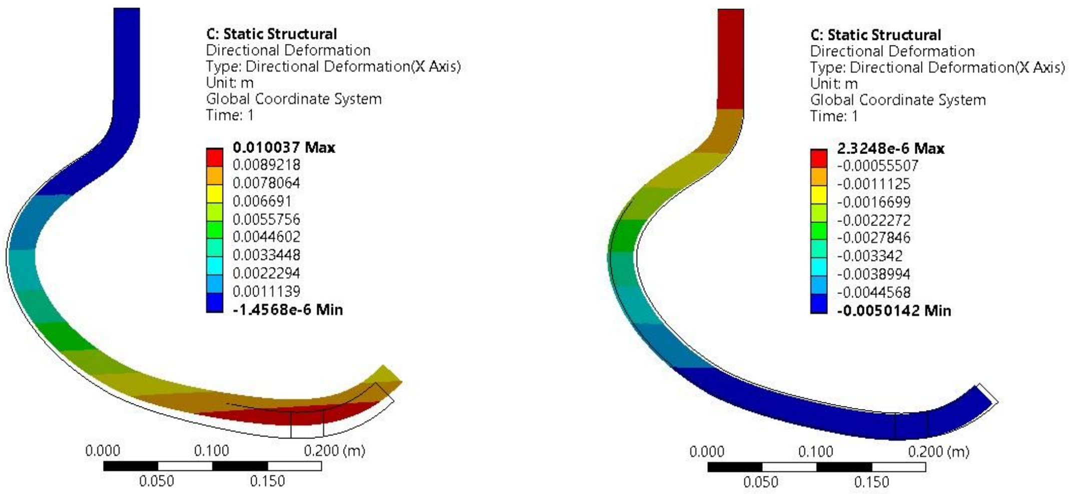

Figure 5 – Prosthesis Deformation. Left: Case A. Right: Case B. (true scale)

4. CONCLUSIONS

In this work, we presented a numerical model for structural evaluation of a “flex run” prosthesis type for people with transtibial amputation, comparing the viability of the use of composite materials using sisal natural fiber. The model was analyzed numerically through the Finite Element Method using the ANSYS software. The simulations were performed based on the prosthesis shape, verifying the loads applied in on the prosthesis during a work situation and its response for different configuration of loads. The results obtained for the use of sisal fiber showed to have an equivalent behavior when compared with the composites already used on the type of prosthesis. The magnitude and location of maximum stress loads, as long the resulting deformation, can make possible an effective design of this component, in order to obtain a light and strong prosthesis, with low fabrication cost.

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6. RESPONSIBILITY NOTICE

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