Design and Simulation study of pineapple leaf reinforced fiber glass as an alternative material for prosthetic limb

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Abstract: In today’s world humans are in rat race due to which they don’t take care of their health due to which they tend to have improper bone growth density and growth this leads to number of fracture and in severe cases amputation due to lifestyle diseases in extreme cases and in cases of accidents. Prosthetic limbs are artificial limbs that are used to replace the original human limbs which a person lost due to any injury, accident and disease. It was found that there is a adhere need to find an optimized cost-effective method for amputated athletes so that they can run at same efficiency with their artificial limbs. This is very expensive medical equipment and its reliability is not that great so taking that into consideration there was a need to find an alternative design or material regarding the same. As the world is going towards bio degradable and bio composite as it is easy to work with, ecofriendly and same time inexpensive. There are many bio composites to choose from sisal, banana leaf, hemp, jute, bamboo etc. There is a desire to make this limb available to the last person without minimal change in impact so this sample went for compressive strength, tensile strength flexural, density, impact, hardness, and wear. So, it was concluded PALF as an alternative material due to its good mechanical properties.

1. INTRODUCTION

In today’s human life 1 in every 100 people lose one or more of their limbs due to many reasons ranging from war, disease, accidents etc. There were several research articles mentioning of the after effects of the accidents [1-5]. A major research in this field revealed that more than 60 percent of the people in India can’t afford the prosthetic limb in India due to its exceeding cost. The cheap option like Jaipur leg is less effective and lead to catastrophic results on the lower back and leg in future which could lead to even more damage. Currently Carbon reinforced polymer which is sturdy, tough and is pretty sustainable is used in 8/10 cases all over the world yet due to its cost most people in India and developing countries can’t afford. To add to it is not environment friendly. In today’s world when there is a need to find eco-friendly alternatives for everything, which helps the environment as well as user While selection, there were many options to choose from ranging from root to fruit of plants in its single fiber form to powder form. A number of experiments were conducted on various materials to find their properties like density, poisons ratio to young’s modulus etc. There were a number of constraints like it had to light, sturdy, take up to 80 kg weight and can make them lead a normal life that is they can walk, jump and run. Also this material should be pocket friendly and also should not lead to heat burns and rashes as it is found in cases of athletes[6].In cases of carbon fiber it is found that it lead to small effect on your coxa and gluteal region in longer run[8,10]. After keeping all mechanical and design constraints an optimized solution by redesigning the limb and at the same time changing the material to PALF was obtained, thus making it remain still sturdy to our given requirement. Virtual prototyping and analysis of the given components was done.
2. STRUCTURE

During our virtual prototyping it was found that by tweaking the design a little and changing the design from cheetah limb design the load could be distributed more effectively. So, redesigning the structure of kneel of the limb optimizing it by changing the design to optimized limits keeping all structural constrains in mind was done. A comparative study of all the designs from 2000s to 2019 was done and after doing our thorough study a problem was found that there is problem in distribution of load from ankle region to your knee portion due to which a person’s ilium and pubis region are under acute pressure which could lead to injuries and problems in future [7]. After studying the legs of different animals, pronghorn leg were shortlisted and redesigning the complete kneel was done so that all the constraints could be resolved[9]. An better distribution in load was found by changing the angle from 21 to 30 degree so that design could be optimized better and less pressure on persons coxa, thus bio mimicking the feet shape of a Pronghorn so that an optimized design could be attained which could be easily suitable and readily available for athletes to give best of their performance as shown in Figure 1 and it should act as tool to aid there growth and effectiveness and lead to better results of athletes during their sprints weight of athlete was assumed to be 80kg for our analysis. Analysis of the normal walking and jumping pattern was also carried out.

![Figure 1. Proposed design](image)

3. MATERIAL SELECTION

Currently the limbs that are used around the world are either made up of some alloy or made up of wood or carbon fiber. All of the above process has a lot of problems like for alloy there is chances of corrosion then its manufacturing process is not good for environment, where wood led to deforestation and finally carbon 385 cannot be degraded easily and once it gives away it harms the environment pretty badly and up to a great extent. So, a want for a material which is effective by its material properties that is strength, flexibility, hardness, compressive and impact loading in a right proportion was there, which had to be fulfilled. So to do the same extensive testing on various materials in Micro UTM were conducted to obtain the various properties i.e. Density, poisons ratio, young’s modulus, rigidity modulus, ultimate tensile strength, compressive strength, flexural strength, wear and elongation[11]. The exhaustive literature survey ended up in identifying seven feasible materials as shown with properties in table 1. This led to shortlisting a few option from our set of bio materials. This was followed by multiple virtual test on the materials to find right material which helps to overcome all the constraints and at the same time find the right material result to be used with our design change to get righteous results. After following the above procedure, it was found that pineapple leaf in long fiber form as compared to short fiber as it is very tough to control due to its direction and orientation which led to brittle nature. Also, by placing it in longitudinal way with small diameter led to better mechanical properties when compared to transverse and random way and it had all the required properties that was needed, as well as by increasing diameter led to more tensile
concentrating defect Figure 5. Now a composite for this which could lead to optimal solution was needed, by again doing extensive testing it was found that PALF (shown in table 2) gave all the properties which were required from it in material physical testing by Micro UTM. All the found results were cross verified by use of ANSYS tool for virtual testing after inputting basic values like density, poisons ratio and young’s modulus. Our material also had fit in the pocket of the maximum patients in developing countries so this material clearly fulfilled all our requirements. This was tested for different compositions and the best composition was chosen.

Table 1. Materials that were considered for testing

| Material       | Young’s Modulus (Gpa) | Tensile Strength (Mpa) | Flexural strength (Mpa) |
|----------------|-----------------------|------------------------|------------------------|
| Absca          | 41                    | 500-700                | 40.24                  |
| Pineapple leaf | 127                   | 6.51                   | 21                     |
| Stem of Corn   | 95.8                  | 74                     | 17.4                   |
| Bamboo         | 5.25                  | 100-800                | 76.5                   |
| Coconut shell  | 855                   | 30.6                   | 46.5                   |
| Flex           | 60                    | 345-1035               | 4.3                    |
| Hemp           | 30-60                 | 400-938                | 54                     |

Table 2. composition of PALF

| Components   | Percentage |
|--------------|------------|
| Holocellulose| 83.6%      |
| Cellulose    | 62.7%      |
| Hemicellulose| 21%        |
| Lignin       | 5.6%       |
| Ash          | 4.5%       |
| Moisture     | 79.6%      |

4. PREPARATION METHODOLOGY

Firstly, the pineapple leaf fiber is taken and it is treated with Na-OH solution for one hour, then the fiber obtained is naturally sun dried for more than 6 hours, then this dried fiber is sliced into small pieces. Similar process is carried out with the pineapple leaf fiber which were not treated by any Na-OH and then sun dried for more than 6 hours and sliced into small pieces is taken as sample 2. Again, the step was repeated for natural leaves which was not sun dried and was in its wet state and this was again sliced into smaller pieces and taken as sample 3. And finally, by taking sample 4 as a pineapple leaf which was dried artificially in oven for 24 hours at 40°C this was also sliced into short fiber form. The treated fiber is mixed with proper ratio of resin where the resin is epoxy. Here different samples ranging from 5 percent to 40 percent fiber to matrix by weight method are obtained and mold is created. The process of mold is done by hand layup process. In this case the mold is kept for drying in a hot plate at a temperature of 140°C for 2 minutes. After removing the mold from hot plate, the limb was cured in oven again at 120°C of temperature for 8 hours.

5. PHYSICAL TESTING

Sample testing of first all our specimens in varying proportions was done and finally went with 10 percent ratio. Which was finally tested with sample structural steel, Femur bone from bone set and carbon 395 for various test to check its tensile, compressive, wear, flexural and impact testing as follows

5.1. Tensile testing

The strength of pure PALF composite was determined by using a Tinius Olsen. The test was carried out according to ASTM standard D3039, using an 800N load and 1 mm/min crosshead speed. The temperature was at room temperature. The specimens were thin rectangular strips of 120 X 20 X 3 mm width, length and thickness, respectively. The tensile strength and modulus values reported here correspond to the average of six samples. The details of extracted data after experimentation shown in
5.2. Flexural testing
Flexural tests of pure PALF composites was performed using a Tinius Olsen universal testing machine at room temperature. Here three-point bending tests was carried out according to the ASTM D790 standard. Here final value was found out by taking six specimens per test condition were tested. The crosshead speed was set to 1mm/min for all tests.

5.3. Izod Impact Strength Test
Impact strength of pure PALF composites was measured using an impact testing machine. For the Izod impact test, samples were cut to the dimension of 70*15*8 mm by using a saw into 6 equal pieces for testing purpose. For each type of composite, six identical samples were tested at ambient conditions according to ASTM D256 and their average value was noted.

Table 3: Values obtained after testing

| Young's modulus in X (Gpa) | Young's Modulus in Y (Gpa) | Young's Modulus in Z (Gpa) | Poison ration in XY | Poison ration in YZ | Poison ration in XZ | Shear modulus in XY | Shear modulus in YZ | Shear modulus in XZ |
|----------------------------|---------------------------|---------------------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|
| 62100                      | 62100                     | 62100                     | .37                | .37                | .37                | 40710              | 40710              | 40710              |

6. VIRTUAL ANALYSIS OF THE MATERIAL

After redesigning the limb completely by mimicking pronghorn and also changing the angle to 30 from 21. It was found that there was a need to had completely rejected the cheetah limbs that used to mimic the way cheetah used to run which was developed by GeorgiaTech. As our material had to be cheap to compliment the design 6 materials were taken into consideration and finally settling for PALF. This was followed with a comparative study for 4 materials that are PALF, Structural Steel, Carbon 395 and Calcium in its pure form from a human femur bone for the model is taken into consideration, coarse meshing for it was done to get all our element and nodes and then proceed with our testing as follows. Firstly, directional deformation test was done and is highlighted in Figure 2 (a)-(d). In these cases, it was seen that difference in Directional deformation of Carbon 395 and PALF is negligible and it is least in case of structural steel. Next, principal strain test was seen as in Figure 3 (a)-(d) the results were similar as earlier stated directional deformation. Third analysis was carried on the basis of Principal maximum stress obtaining the same result that carbon fiber and PALF stress is negligible as in Figure 4 (a)-(d) and finally the total deformation test whose result showed that structural steel was best suited material for it and result of carbon fiber and PALF was better than calcium as in figure 5 (a)-(d) but still preference for carbon fiber or PALF over steel is there because steel might rust and its life expectancy might be less. This tends to complement our design completely and thus leads to better and effective results. The analysis results were validated for h-type (element size) and p-type (element order) methods [12,13,14]. The symmetric nature of the deformation plot depicts the corrective measures of loads and boundary conditions [15,16]. The von-mises stress plot results seem to be accurate based on the convergence theory and compatibility equation which is decided based on the number of iterations carried out for each of the case [17,18].

6.1. Directional deformation
For this testing was carried out for four cases in order PALF, Structural Steel, Carbon 395 and finally calcium from femur bone by applying 800N in Y direction and there was intend to find the directional deformation in X direction applying it on kneel and at its base keeping the 2 flexible entities at its base as rigid. This led to having only deformation in Z and X axis direction. The deformation in Z direction is comparably negligible when compared to X direction so considering that for the sake of our study. Here after studying all the four cases it could be conclude that maximum deformation was observed in case of calcium and least in case of structural steel. Here it was seen that the deformation in Carbon 395 and PALF is comparable and one can replace other if this is the criteria for judgement. The report made due to this study is in comparable to our study from physical cases with a variation of only 5-6
In this test principal stress force of 800N was applied on the body in Y direction which is perpendicular to our area in consideration. In this there was a need to find the elongation and maximum ultimate strain value to compare with our physically test achieved value. After the value testing was done, it could be concluded after looking at our results it could be seen that maximum displacement was in case of PALF and minimum in case of structural steel. As the variation in case of calcium and Carbon 395 is comparable so that is why tend to make prosthetic limb out of it but still the value obtained in case of PALF is pretty long so it will not fail that easily and can up to infinite cycles. Also, the values obtained in this case corresponds to values obtained in theoretical calculations which were obtained after physically testing with a 4.73 percent variation. Also due to design change our two extended fins tend to give a damping factor and spring effect which doesn’t affect the body yet gives a spring back effect which led to giving him an edge while running and cushion effect while jumping.

6.3. Maximum principal stress

For virtual testing in this case 4 samples were taken and a force of 800N was applied on it along its perpendicular direction i.e. Y axis. After application of load it was found that its compressive strength, Poisson ratio, and Young’s modulus in this case and compare and comprehend all the results that were obtained for reference purposes. In this case it was found that the best value is given by calcium.
followed by structural steel and worst in case of PALF. It was seen that the value is worst in PALF in comparison to other three samples but it is yet over .81Mpa value which is our value for safety. So, it could be used in spite of not up to values. The values when compared with physical test obtained properties is compared with values found through virtual testing are within area of errors with a deflection of 6.7 percent values.

6.4. Total deformation of samples

![Image](imageURL)

**Figure 5.** a. Directional deformation a. PALF b. Structural Steel c. Carbon 395 d. Calcium

In this case a load of 800 N was applied in perpendicular direction and try to obtain its fracture point, life cycle, wear point, Poisson’s Ratio, shear modulus and deflection in X, Y and Z direction[19]. In this testing various case test were run and results were comprehend after application of the load on the kneel and upper base of the limb under consideration keeping the fins and lower base as a fixed entity. This fins due flexibility of PALF when the ratio is less tends to give a damping and cushion like effect for load applied in y direction and gives back a spring back effect which tends to help in better dissipation of load over the body of kneel and less pressure will have to borne by coxa or ileus of the human body. This will help in keeping the body under least load possible. In this case least deformation was obtained in the case of structural steel and maximum in PALF. In this case PALF was found to be having maximum deformation yet it can sustain infinite life and not do any damage to the health of the human gluteal region. Which was found to be prevalent in case of other structural steel and carbon 395. All feasible materials compared with experimental to simulation validation and were discussed in table 4.

| Material     | Principle stress (in Mpa) | Principle elastic strain (in mm) | Total deformation (in mm) |
|--------------|---------------------------|---------------------------------|--------------------------|
| Palf         | 2.8972e-5                 | 0.8529                          | 0.00011692               | 0.0018869 |
| Structural steel | 8.0472e-6               | 1.2207                          | 5.2475e-6               | 6.8813e-5 |
| Carbon 395   | 2.004e-5                  | 1.06858                        | 9.5558-5                | 0.0013663 |
| Calcium      | 9.1197e-5                 | 1.2351                          | 5.919e-5                | 0.000075568 |

7. MATERIAL COMPOSITION OF PALF

PALF was selected over other materials taking in account its material properties, price and all other constraints in consideration, by getting acquit to the chemical composition of the PALF for better understanding when compared with other given bio composites. After referring to table 1 and 4 to find relevant data about the different bio fiber for readily usage and comparison of selecting bio composite over the other material. To verify lab data by virtual data first the young modulus was found followed by ultimate stress, tensile load, flexural stress and elongation etc. Then by mass faction method we tend to form its polymer matrix with glass fiber. Adding resins to epoxy in 1:10 ratio and with 10 percent Na-OH. This shows the ultimate force, stress and modulus of pineapple leaf when put under tensile testing. For this naturally dried sample of pineapple leaf was used and using ASTM standards it
was put under tensile testing.

8. ANALYTIC CALCULATION

The elastic properties of the composite are calculated using the rule of mixture equations. It is a conveniently easy way to estimate the material properties, i.e., the module different directions of a composite. In this composite was defined by volume fraction along with the young’s modulus in different direction.

\[ E_{1}^{udf} = E_{f}V_{f} + E_{m}(1-V_{f}) \] (1)

In this appropriate proportion of fiber glass and pineapple leaf were taken in the appropriate ratio of 1:10 in volume fraction to get the expected result. (Figure 6)

9. CONCLUSION

From extensive testing and virtual simulations following conclusions can be drawn

- coxa or gluteal of human body. We just need to customize the proportion of Pineapple leaf in Fiber glass according to the age and weight of person.
- The expensive material used till date is Carbon 395 were as PALF is half of the cost.

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