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Indegenous material for prosthetic limb's side clamp analysis

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ABSTRACT

Various mobile devices can be used for amputees who lose a limb due to congenital defects or bone deformities. Prosthetics is the rapidly changing field involving orthopedic supports and artificial limbs. The prosthetic limb resembles a human leg in function and appearance. In recent years computers have been used to help fit amputees with prosthetic limbs. Prosthetic facilities use Computer Aided Design of modeling the patient's arm or leg. For the design to be optimal, it should have less weight at optimal strength. Hence the materials with high strength that can be used for manufacture of various parts of a prosthetic limb are also studied in this paper. Various parts of the prosthetic limb are designed and assembled. The design and development of a side clamp has been studied and its deflections when forces applied are considered. Materials for different parts of the prosthetic limb are studied. The analysis of a side clamp used in the design of a prosthetic limb is undertaken and an optimal design for the side clamp is proposed. Aluminum alloy and magnesium alloy and composite materials like glass epoxy and boron epoxy are considered for analysis. The design and analysis is done using CATIA.

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KEYWORDS

Prosthetic limb;
Alternate material;
Glass epoxy polymer composites;
Boron epoxy polymer composite;
CATIA analysis.

INTRODUCTION

Prosthetics and orthotics are the rapidly changing fields involving orthopedic supports and artificial limbs. Orthotics is the designing, fitting and manufacturing of orthopedic supports for individuals with disabling conditions of the spine and extremities. Prosthetics is the designing, fitting and manufacturing of artificial limbs for people with limb loss. When someone loses an arm or a leg, or part of an arm or leg, the lost part can be replaced with an artificial limb called *prosthesis*. Prosthesis makes it possible for the person to return to a near normal lifestyle, doing just about anything a normal person can.

In prosthetic design following functions are main components

- Evaluate, design, fabricate, fit and align prostheses
- Select materials and components
- Make casts, measurements, model modifications and layouts
- Perform fittings, alignments and adjustments

In recent years computers have been used to help fit amputees with prosthetic limbs. Eighty-five percent of prosthetic facilities use CAD/CAM to design a model of the affected limb to prepare a mold for the new limb.

Need for designing artificial limbs

In developing countries like India, road accidents inflict grievous injuries on people. Loss of a limb by amputation can be very traumatic. Other factors such as congenital defects, bone deformities and constricted bone growth also add to the number of physically challenged people.

In India, commonly used artificial legs are of exoskeleton type made of high density polyethylene. Though the imported endoskeleton types of limbs are available in India, they are very expensive. As physical deformities aggravate the economic woes of victims in our country, it calls for an indigenous development to restore the functional normalcy of physically challenged people at an affordable price.

Modern methods of designing artificial limbs

Modern industrial fabrication, particularly with injection molded plastics, can create lightweight, low cost components with sufficient function. Designs can be made moisture resistant also. The lower manufacturing costs of such devices permit their use in developing economies.

In recent years researchers have developed a variety of thicker gel materials that add a measure of cushioning and pressure dissipation while retaining the benefits of the original liners (Figure 1). The same gel cushioning technology has also been adapted to bicycle seat coverings and similar non-prosthetic applications.

Characteristics of artificial limbs

- Assist a smooth and comfortable walking for a unilateral amputee.
- Chemically powered, like natural muscle, and exceed the force generation, contraction and speed of their natural counterpart.
- Help the amputee walk with normal gait
- Give comfort to the amputee
- Light weight
- Good cosmetic appearance
- Ease of operation

Raw materials used for prosthetic limbs

The materials used in artificial limbs include willow

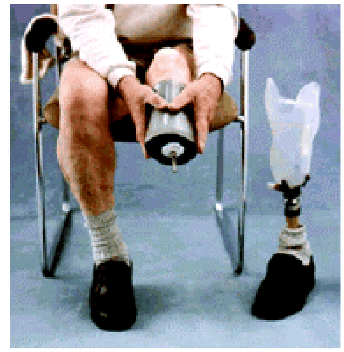


Figure 1

wood, laminated fibers and plastics, various metallic alloys, and carbon-fiber composites. One model of artificial leg is made of layers of stockinette cloth coated with plastic; it has duralumin joints at the knee and ankle, rubber soles on the feet, and a leather cuff cushioning the stump. The cuff fits around the thigh like a corset, holding the artificial leg firmly in place, and connects to a leather belt around the waist. Often, spring joints are employed on foot pieces to give natural-looking movements. Microprocessors and an array of sensors are used to operate the mechanical and hydraulic system of some artificial legs, providing more natural locomotion. Artificial legs may also be secured by suction between socket and stump.

A typical prosthetic device consists of a custom fitted socket, an internal structure (also called a pylon), knee cuffs and belts that attach it to the body, prosthetic cushion at the area of contact, and in some cases, realistic-looking skin.

A prosthetic device should most of all be lightweight; hence, much of it is made from plastic. The socket is usually made from polypropylene. Lightweight metals such as titanium and aluminum have replaced much of the steel in the pylon. Alloys of these materials are most frequently used. The newest development in prosthesis manufacture has been the use of carbon fiber to form a lightweight pylon.

Certain parts of the limb (for example, the feet) have traditionally been made of wood (such as maple, hickory basswood, willow, poplar, and linden) and rubber. Even today the feet are made from urethane foam with a wooden inner keel construction. Other materials commonly used are plastics such as polyethylene, polypropylene, acrylics, and polyurethane. Prosthetic socks are made from a number of soft yet strong fabrics. Earlier socks were made of wool, as are some modern ones, which can also be made of cotton or various synthetic materials.

Physical appearance of the prosthetic limb is important to the amputee. The majority of endoskeletal prostheses (pylons) are covered with a soft polyurethane foam cover that has been designed to match the shape of the patient's sound limb. This foam cover is then covered with a sock or artificial skin that is painted to match the patient's skin color. Artificial arms, not having to support the weight of the body, may be made of lighter metals and plastics. They are usually strapped and controlled by a harness. Prototype bionic arms have been developed that permit a person to use thought to control the limited movements of the motorized prosthesis. The commands are transmitted through chest muscle that has been surgically connected to the remaining nerves associated with the lost limb; electrodes linked to the artificial arm convert the sensed electrical signals of the muscle into arm movement.

Lower limb orthotics (Calipers)

Lower limb Orthotics or Ankle foot orthotics are of three types:

1. Ankle foot orthosis with limited motion of Orthosis (Figure 2)
2. Knee Ankle Foot Orthosis (Figure 3)
3. Hip Knee Ankle Foot Orthosis (Figure 4)

Design and assembly of prosthetic limb

Figure 2

Figure 3

Figure 4

Components of prosthetic limb

Shoe, Bottom Foot Clamp, Top Foot Clamp, Foot Clamp Plate, Plastic Clamp, Side Clamp, Upper Clamp, Fasteners.

Analysis

Figure 6 shows the position of the legs when a person is walking .The position of leg above the red part indicates where the maximum weight of the person falls on the leg i.e. the red colored portion indicates that a person is about to place his leg on the floor (first and last positions) or the person stands on one leg (second position) and raises the other in an attempt to step further. In both these cases, maximum weight of the person falls on one leg. Other positions (positions of leg above the green portion) indicate that the weight of the person is distributed between the two legs. These positions indicate that the person is raising his leg.

In this paper, analysis is done taking the maximum walking positions of a person i.e. positions where the maximum weight of the person acts on one leg (positions first, second and last in the figure 6). The side clamp of the prosthetic limb is taken for analysis as it supports the prosthetic limb. The entire weight of the person falls on the two side clamps present on either side of the prosthetic limb. The total weight of the person is distributed equally on the two side clamps when the person is in standing position. This weight of the person is taken as the force acting on the two side clamps. For example, if the weight of the person is 100kg, the total force acting on the two side clamps is 100*10 (acceleration due to gravity in m/s^2). Therefore, the total force acting on the two side clamps is 1000N.This force of 1000N is distributed equally between the two side clamps when a person is in standstill position. But when the person is walking, the distribution of force between the two side clamps varies from a maximum of 1000N (when the entire force acts on one clamp) to a minimum of 0N (when no force acts on the clamp). Since there are two side clamps present on the

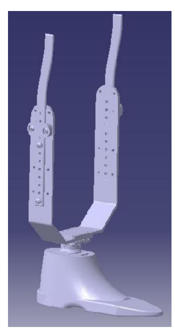
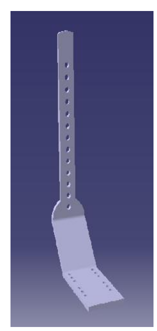
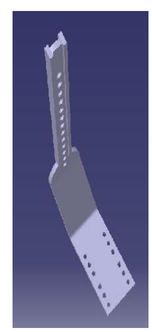


Figure 5



Design 1



Design 2 (I-section)

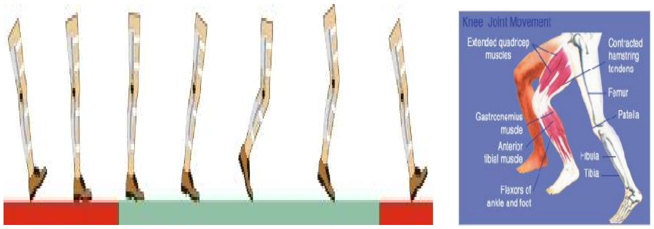


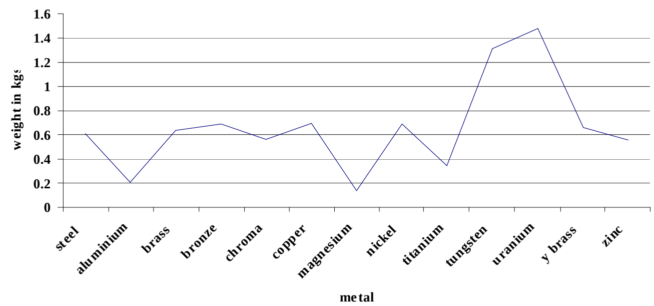
Figure 6 : Walking position for one step

either side of the prosthetic limb, half of the force acts on each side clamp at the maximum condition. Assuming the maximum weight of the person to be 100kg and maximum force acting on both the side clamps to be 1000N,force acting on each side clamp is obtained as 1000/2 i.e. 500N. So, a force of 500N is applied on the side clamp, by applying constraints at the required position (positions where the bolts are fixed).

In order to calculate the stresses acting on the clamp, a distributive force is applied on the clamp in the vertical direction to the bolt. So, vertical force acts on the two bolts. While applying the force of 500N on the side clamp, total of 500N is applied on the two bolts at a time and a combination of forces, which amounts to 500N, is applied at both bolts separately. For example, if a force of 100N is applied to the upper bolt, a force of 400N is applied to the lower bolt thus making the sum to be 500N.In this way; a distribution of force is caused at both the bolts. By applying this distributive force, we can know the variation in the maximum and minimum stresses that are generated in the clamp. But in both the cases i.e. in case where total force is applied at both bolts combinely and in case where part of the load is applied to the upper bolt and the remaining part is applied to the lower bolt, the same values of maximum stress is generated. Change is seen only in the minimum value of stress generated.

Since the material of the existing side clamp is steel, analysis is done first on this metal and the permissible stress limits are obtained. These stress limits give the maximum and minimum values of stresses that are generated on the side clamp when a particular force is applied on it. The maximum value of the stress generated is then compared with the ultimate tensile strength of steel. For a safe design, the value of stress generated during the analysis should be lesser than the actual tensile strength of steel.

Various other metals and composites which have

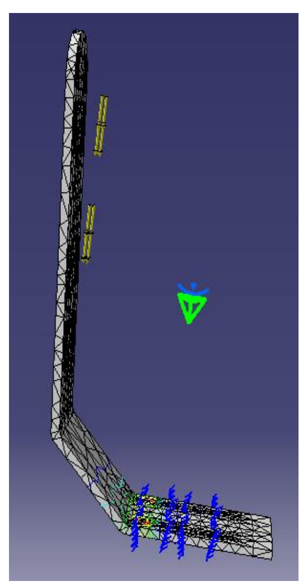


Comparision of weight for the existing design of side clamp

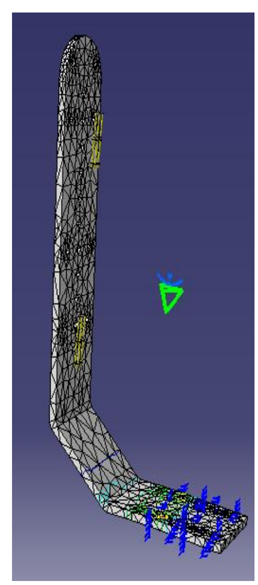
lesser weight than steel are taken into account for analysis since the major aim is to reduce the weight of the side clamp.

The above graph shows the comparative weights of different metals applied to the existing design of the side clamp. From the graph, it can be observed that the weight of aluminum and magnesium is much lesser than steel and even lesser than many other metals that are taken into account. So, among the metals the preferable materials that are taken into analysis are aluminum and magnesium.

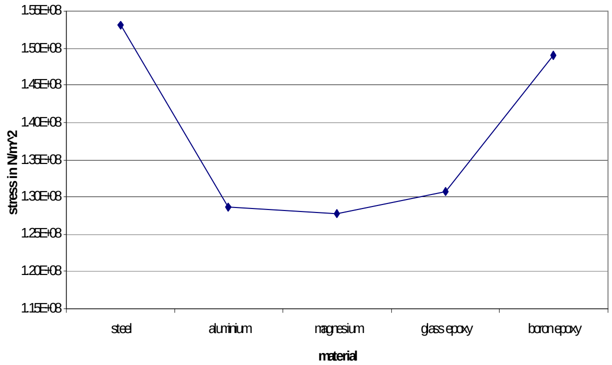
Both the metals aluminum and magnesium are analyzed in the same way as that of steel. The values of maximum stresses that are generated in both these metals is compared with that of steel .It is found that the maximum stress generated is more in steel when compared with aluminum and magnesium.



MAGNESIUM
Force 500N
Max Stress: 1.278e+008N/m^2
Min Stress: 239543N/m^2



GLASS EPOXY
Max Stress: 1.31e+008N/m^2
Min Stress: 7207.67N/m^2



Maximum stress in the existing design side clamp

Considering the advantages of composite materials over pure metals, two materials namely glass epoxy and boron epoxy is taken for analysis. The values of stresses that are generated in the analysis are compared with the tensile strength of the respective composite materials.

Maximum stresses generated in the side clamp

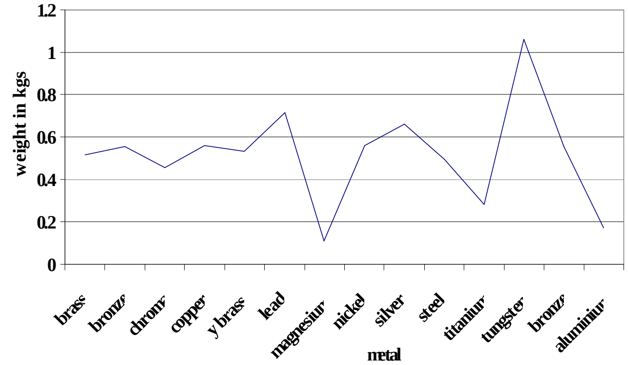
The above values of stresses that are generated in the side clamp are lesser than that of the tensile strength of the respective materials. Hence, the above materials are safe materials and can be chosen as materials for the side clamp.

Analysis for the proposed design (I-section)

An alternative design for the side clamp is the I-section wherein the rectangular section of the side clamp is replaced by the I-section of the side clamp. The moment of inertia and the bending moment of the rectangular section and the I-section are calculated. It is found that the moment of inertia obtained for the I-section is lesser than that of the rectangular section. In case of bending moment the load to be applied (w=1000N) taken for calculation. The values obtained for both the designs are same since the length of span is same for both rectangular and I –section and the same force 1000N is applied to both the sections.

Therefore the I-section is considered as a better cross section for the side clamp when compared with the rectangular section since its moment of inertia is much lesser than the rectangular section.

In the analysis of I-section also different materials are applied to the side clamp and the materials with less weight are taken for analysis. Graph shows that for aluminum and magnesium lower values of weights are obtained when compared with other metals.



Comparision of weights for the proposed design (I-section)

Calculation of moment of inertia for the rectangular and I-section

Moment of inertia of the rectangular section:

$$\mathbf{I = \frac{bd^3}{12} = \frac{(4.9)(48)^3}{12} = 45158.4mm^4} \quad (1)$$

Moment of inertia for the I-section:

$$\mathbf{I = \frac{BD^3}{12} - \frac{bd^3}{12}}$$

$$\mathbf{= \frac{(10)(20)^3}{12} - \frac{(5.1)(12)^3}{12}} \quad (2)$$

$$\mathbf{= 6666.67 - 734.4 = 5932.27nm^4}$$

Calculation of bending moment for rectangular and I-section

The value of bending moments for the rectangular and I-section is given by the formula maximum bending moment, M = wl

Where,

w = load applied (1,000 N)

l = length of span (82.26mm)

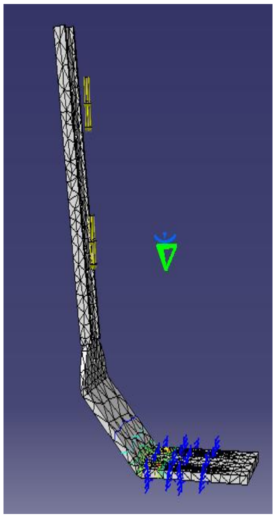
Hence, the maximum bending moment,

$$\mathbf{M = 1,000 \times 82.26 = 82,260\ Nmm} \quad (3)$$

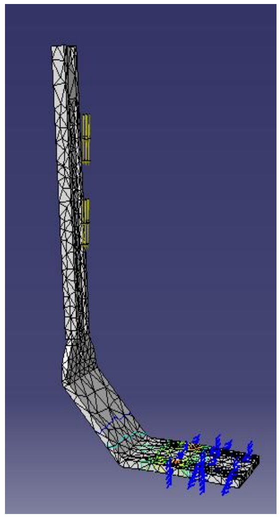
The above stresses that are generated in the side clamp when that particular material is applied to the side clamp are lesser than the tensile strength of the respective materials. Hence the design for I-section is a safe design for all these materials.

Analysis for design-1

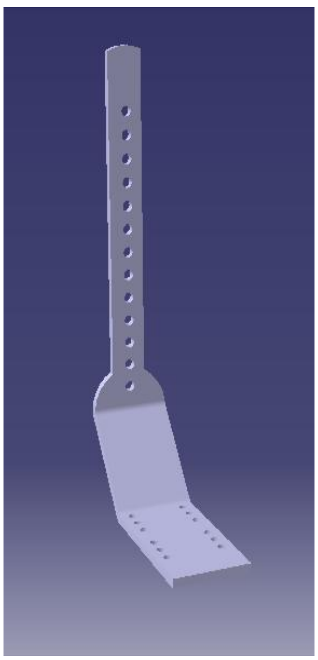
For the Design-1 of the side clamp, the thickness of the rectangular section is decreased. Analysis is done by decreasing the cross section of the rectangular section. But the deflections that are obtained in this case



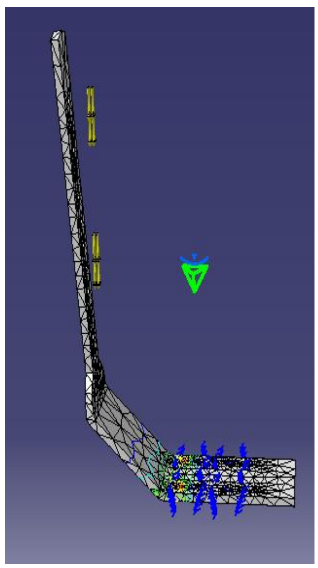
MAGNESIUM
Max Stress: 1.161e+008N/m^2
Min Stress: 382.54N/m^2



GLASS EPOXY
Max Stress: 1.2304e+008N/m^2
Mini Stress: 5580438 N/m^2



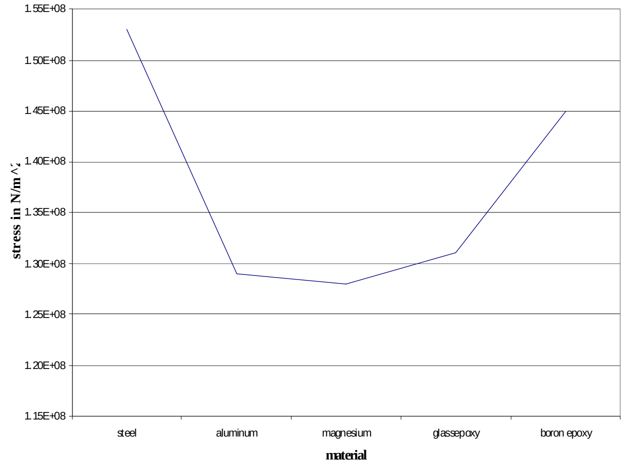
Design 1 of the side clamp



Deflections in the side clamp, Material: steel, Maximum stress:6.63e+008N/m^2, Minimum stress: 21310.3N/m^2

(for steel) exceeded the tensile strength of steel. This showed that decreasing the thickness should not be the only criteria for a better design. Strength factor should also be taken into consideration for getting a better design.

The above values of maximum stress that is generated in the proposed Design -1 of the side clamp exceeded that of the ultimate tensile strength value of steel, which should be at the maximum of 5.5e+008N/m^2. Hence, by decreasing the thickness of the rectangular section, there is a chance that that the side clamps may



Maximum stress in the proposed design (I-section)

TABLE 1 : Showing the comparison of weights when a particular metal is applied to side clamp

Metal	Existing design(Kg)	Proposed design(Kg)
Steel	0.612	0.495
Aluminum	0.211	0.171
Magnesium	0.14	0.113
Brass	0.64	0.518
Bronze	0.69	0.558
Chroma	0.56	0.453
Copper	0.693	0.561
Lead	0.883	0.715
Nickel	0.691	0.560
Silver	0.817	0.661
Titanium	0.347	0.281
Tungsten	1.313	1.063
Uranium	1.485	1.202
Yellow Brass	0.659	0.534

TABLE 2 : Properties applied materials

	STEEL	Al	Mg	Glass epoxy	Boron epoxy
Young's Modulus	2e+011	7e+010	4.481e+010	3.86e+010	2.06e+011
Poisson ratio	0.266	0.346	0.35	0.26	0.23
Density - kg/m3	7860	2710	1798	1810	2000
Thermal expansion	0.0000117	0.0000236	0.0000288	0.00007	0.00006
Yield strength N/m2	2.5e+008	9.5e+007	2.75e+008	3.40e+008	15.2e+008

break when a man of 100kg is fitted with the prosthetic limb having this side clamp. Hence, this design is not considered as a safe design.

Percentage reduction in weight of the existing side clamp when different materials are applied.

- Aluminum: 65.52%
- Magnesium: 77.12%

- Glass epoxy: 76.9%
- Boron epoxy: 74.5%

Percentage weight reduction that is obtained in the side clamp (I-section) with respect to the existing design (steel side clamp) is as follows.

- Aluminum: 72.05%
- Magnesium: 81.53%
- Boron epoxy: 79.41%
- Glass epoxy: 81.37%

CONCLUSIONS

The prosthetic limb designed in CATIA is a lightweight model. Percentage reduction in weight is due to the modified design of the side clamp. The I-section for the side clamp proved to be a better design than the rectangular section in terms of its weight and strength. Metals like aluminum and magnesium are the alternate materials for the side clamp where composite materials like glass epoxy and boron epoxy may also be utilized. For a 0.612kg weight of actual side clamp, reduction in weight of each side clamp due to I-section achieved is 0.117kg resulting in total reduction in weight for the two side clamps of 0.234kg ie., percentage reduction in weight of the side clamp due to I-section is 19.11%.

It is deducted from the experimental results that Magnesium as the material provides highest percentage of saving in the weight compared to other three materials viz., Aluminum, Glass epoxy and Boron epoxy. Among the metals aluminum and magnesium, aluminum is soft when taken in pure form. Hence small alloying elements can be added to make it harder. Hence both these metals can be used as alternate metals for the prosthetic limb.

Epoxy material scores over other materials when mass produced for the reliable performance. Among the composite materials, boron epoxy has high strength when compared with glass epoxy. Boron epoxy and glass epoxy, which are taken for analysis, can be used as alternate materials for the side clamp.

All the four materials that are taken for analysis generated the stress values, which are lesser than the actual tensile strength of the respective materials.

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