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# Analysis of Alternative 3D Printed Lower Limb Prosthetic for Light Weight Design Concept

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**Abstract:- The global market demand for prosthetic limbs is increasing, as it depends on a variety of factors such as the prevalence of limb loss and the availability and affordability of prosthetic technology in different regions of the world. . However, the fabrication of the lower limb prosthetic takes about 4-6 weeks and the prosthetic weighs between 2000g and 4000g. In this context, a lot of research was done on creating low weight lower limb prosthetics using a variety of techniques. However, there hasn't been much work done to create lightweight lower limb prosthetics utilizing 3D printing techniques. In this paper, different models made with lightweight construction and ASTM-tested PLA material were analyzed in order to demonstrate and offer a feasible option for lower limb prosthetics. The compression test analysis was performed on the developed 3D models under static structural conditions, The three models created based on different structure was tested under the boundary condition with a loading force of 1.5kN and the model 1 exhibited stress of 40.133 Mpa, the model 2 exhibited stress of 6.37 Mpa, the model 3 exhibited a stress of 6.58 Mpa for the applied load. The model which exhibited a stress of 6.37 Mpa for the applied load of 1.5 kN was selected and 3D printed. The 3D printed lower limb prosthetic weighs 400 grams which accounts to 80% weight reduction as the conventional lower limb prosthetic weighs 2000 grams and the time taken to fabricate is two days compared to the conventional method which takes about 4-6 weeks. The cost of fabricating the lower limb prosthetic was 4800 INR. The 3D printed lower limb prosthetic can be customized as per the client's requirement.**

## I. INTRODUCTION

Lower limb prosthetics are intended to take the place of a missing leg or foot, restoring mobility and independence to those who have had amputations. These prosthetics' design and analysis necessitate a thorough knowledge of biomechanics and human anatomy. To make sure the prosthetic is both practical and comfortable for the user, engineers must take into account elements like weight, material composition, and energy transfer. The prosthetic must also be customized to the user's unique requirements, taking into account the user's age, weight, and lifestyle as well as the degree of amputation. The prosthetic can also incorporate cutting-edge technologies like sensors and microprocessors to enhance its usability and functionality. In order to develop prosthetics that optimise function and improve quality of life, engineers, clinicians, and users must work together in the complex and multidisciplinary field of lower limb prosthetic design and analysis.

New technologies like computer-aided design and manufacturing are increasingly being used to speed up the development and production of prosthetic sockets [1]. The ability to design and produce distinctive, intricate, and organic structures using 3D printing can speed up the development of such products [2]. However, problems with these products' mechanical characterization and their mechanical compliance with safety regulations still need to be addressed [3], [4]. A prosthesis experiences significant repetitive loading while being used as a result of a complex combination of compressive and bending loads brought on by the weight and posture of the user. Such constant loads may cause the prosthesis to become worn out and ultimately render it unsafe for use. To accurately evaluate the prosthesis' safety, loads that the prosthesis encounters while walking should be thoroughly understood and successfully replicated [5], [6].

According to [7], each component of the prosthesis must meet specific loading-capacity requirements for both static and dynamic conditions. Sadly, the prosthetic socket is not taken into account because it is still a user-tailored part. The socket should be able to withstand at least the same loads as the rest of the parts, so these guidelines can still be used as a guide, as was done in earlier studies [8]. Before using these standards, conventionally made sockets were put through testing, with the results being reported for both below- and above-knee cases [10]. Even some of the conventional products fall short of the minimum standards, according to reports on the socket's load-bearing capacity [11], [12].

The goal of this project was to create a lightweight lower limb prosthetic, and the goal has been achieved. Conventional designs and materials utilized for lower limb prostheses were discovered to require more time to build, to fix mistakes, and to make a perfect, comfortable prosthesis for the patient or amputee. Following this discovery, we created a distinctive design that is quick and simple to construct. It is also strong, trustworthy and economical. While the traditional prosthetic weighs roughly 2 kg, the manufactured model weighs only 400g.

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## II. METHODOLOGY

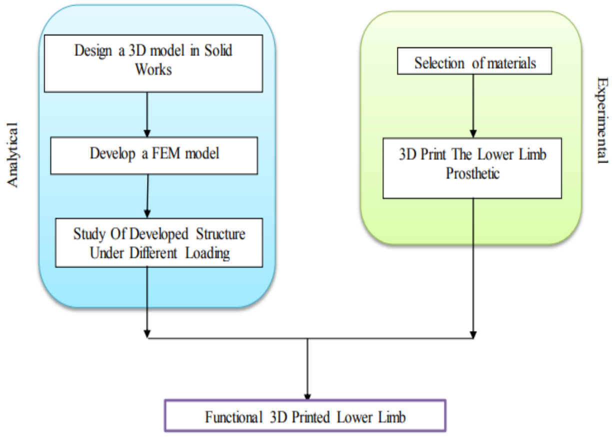

Fig 1 Methodology

The methodology used in this work is shown in Fig.1, where Solid Works software is used for modelling or design. With the help of the solid works software, three different models were created. Then, a variety of test methods are used to choose the material for the prosthetic lower limb. All three models are subjected to a finite element analysis in the Ansys workbench software under static structural conditions. The results are compared, and the most suitable model is chosen. The chosen model is then printed using FDM 3D printer.

## III. SYNTHESIS OF 3D LOWER LIMB MODEL

Polylactic acid (PLA) is a thermoplastic material that is commonly used in 3D printing. It is a strong and durable material that is also biocompatible and biodegradable. This makes it an ideal material for use in prosthetics, as it can be customized to fit the individual patient's needs and will not cause any adverse reactions. The modeling of a lower limb prosthetic using PLA material typically begins with the creation of a 3D model of the patient's residual limb. This model can be created using a variety of methods, including computer-aided design (CAD) software or a 3D scanner. Once the model is created, it can be used to create a mold for the prosthetic socket. The socket is then fabricated using a 3D printer.

Based on the basic concept and requirement of lower limb prosthetic model, three different section model are created using modelling software. The three model created are shown in figure 2-4.

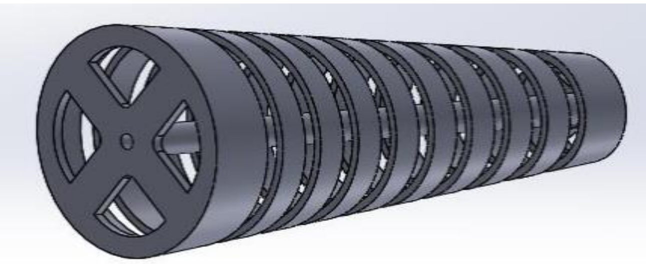
Fig 2 Cross Centric Section Model

The Cross centric section model requires more material and 3D printing time required also more

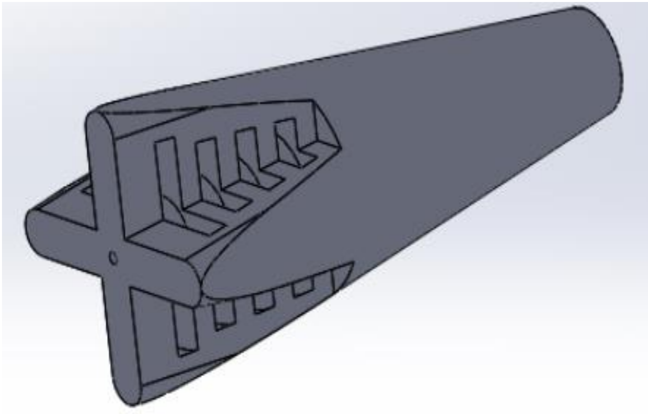
Fig 3 Plus Section Model

The Plus section model requires more material and 3D printing time less compared to model 1

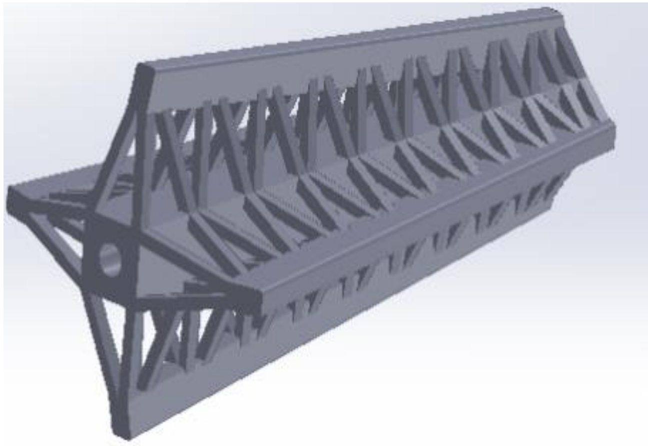
Fig 4 Star Section Model

The Star section model requires less material compared to first two and also time required for 3D printing also less.

## IV. RESULTS AND DISCUSSION

The analysis of lower limb prosthetic helped to identify potential areas of weakness or stress concentrations to optimize the design and ensure that the prosthetic is both strong and durable. Three models generated are subjected to compression test using static analysis to check its design safe conditions. The property needed for software input obtained practically by conducting compression analysis of polylactic acid material for ASTM standards.

Model 1 as shown in Fig 5, generates a stress of around 40.11 Mpa for a load of 1.5kN which more than the ultimate compression strength 32 Mpa of the material and the structure will fail if used

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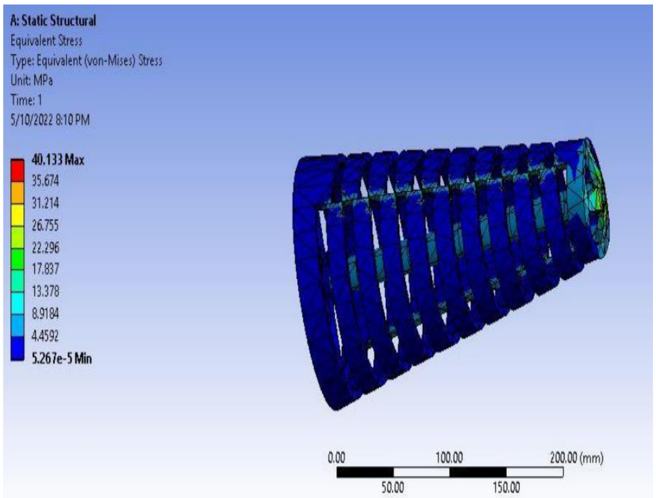

Fig 5 Compression Test Analysis of Circular Section Model

Model 2 as shown in Fig 6, generates the stress of around 6.37 Mpa for a load of 1.5kN which is less than the ultimate compression strength of the material.

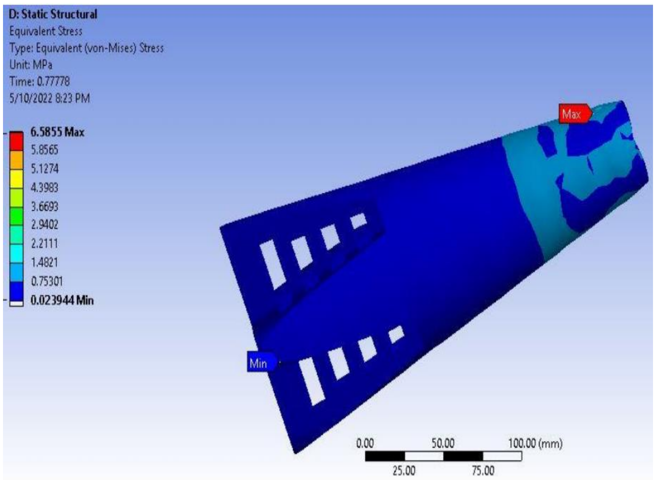

Fig 6 Compression test analysis of X sectioned model

Model 3 as shown in Fig 7, generates the stress of around 6.58 Mpa for a load of 1.5kN which is less than the ultimate compression strength of the material and hence the design is safe.

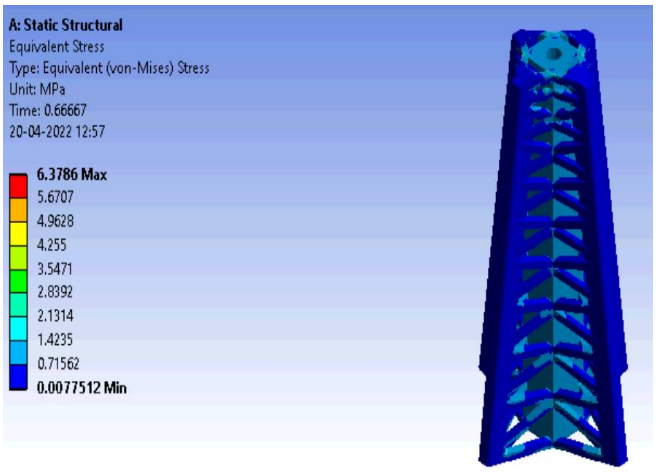

Fig 7 Compression Test Analysis of Star Sectioned Model

The end result of this work was to fabricate a low weight 3D printed lower limb prosthetic and the same has been fabricated as shown in the Fig 7. In the actual practice it was found conventional designs and materials used for the lower limb prosthesis took more time to fabricate, to correct errors and to produce a flawless comfortable prosthesis to the patient or the amputee. After this observation was made, we came up with a unique design which is easy and takes less time to manufacture, the design we developed is also durable, reliable, comfortable and cost effective.

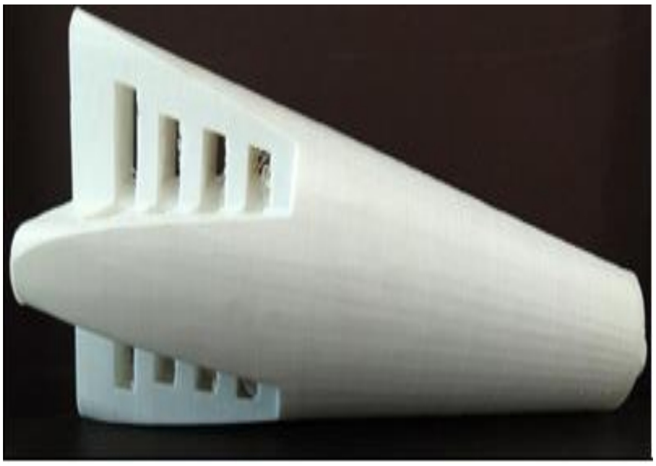
Fig 8 3D Printed lower limb prosthetic

The below table 1 gives the complete specification of 3D printed lower limb prosthetic.

Table 1 The Complete Specification of 3D Printed Lower Limb Prosthetic

| Objective | Specification |
|---|---|
| Material | Poly Lactic Acid (PLA) |
| Total Weight | 400 gms |
| Total Height | 270 mm |
| Major Diameter (below knee) | 125 mm |
| Minor Diameter (above ankle) | 45 mm |
| Hollow Diameter | 20 mm |
| Time taken for printing | 25 Hrs |
| Infill Percentage | 10 |
| Cost of Printing | 4800 INR |

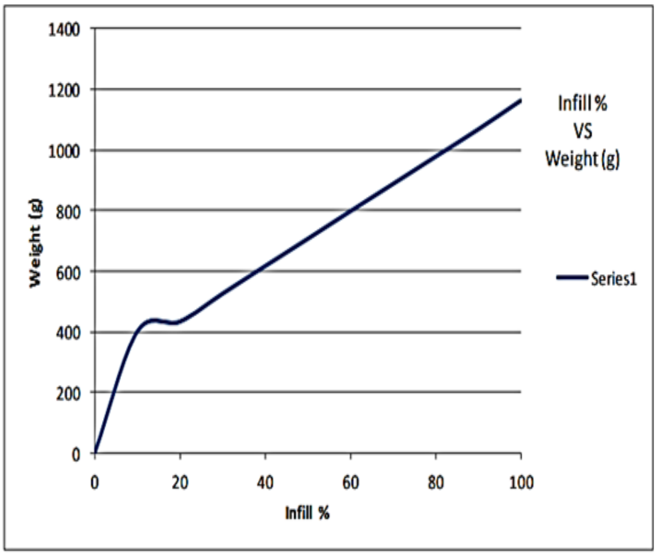


Fig 9 Infill % vs Weight (g)

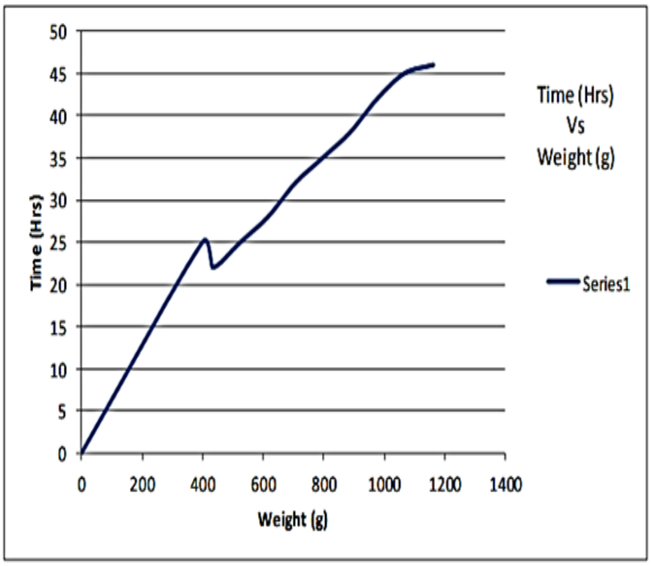


Fig 10 Time (Hrs) vs Weight (g)

The above graph in Fig 9 shows that as the infill percentage increases the weight of the prosthetic also increases. The above graph in Fig 10 shows the time taken for printing as the weight increases that is when the percentage of infill increases the weight increases which intern increases the printing time.

## V. CONCLUSION

The lower limb prosthetic model was first develop in solid works software, the compression analysis was done using numerical software and the appropriate model was selects based on the load bearing capacity and was 3D printed. The cost of 3D printed lower limb prosthetic is around 4800 INR whereas the conventional lower limb prosthetic cost 25000 INR. The time taken to fabricate the lower limb prosthetic is two days whereas the conventional lower limb prosthetic takes around 4-6 weeks. The weight can be further reduced by using carbon fibre which intern increases the cost of the prosthetic this can be used where the client specifically requires low weight prosthetic.

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