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MODELING, ANALYSIS AND FABRICATION OF PROSTHETIC RUNNING BLADE USING 3D – PRINTING TECHNOLOGY

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Abstract: This abstract discusses the development of a prosthetic running blade using 3D printing technology and carbon fiber reinforced nylon material, along with Finite Element Analysis (FEA) to analyze the design. The aim of the study was to create a lightweight and durable prosthetic running blade that could provide a comfortable running experience for amputees. The 3D printing technique allowed for the production of a customized design that fit the patient's specific needs. Carbon fiber reinforced nylon material was chosen for its strength and durability. FEA was used to simulate the stresses and strains that the blade would undergo during use. The results of the FEA analysis showed that the design was able to withstand the required stresses and strains. The final product was found to be lightweight, comfortable and durable, making it a viable option for amputees who require a prosthetic running blade.

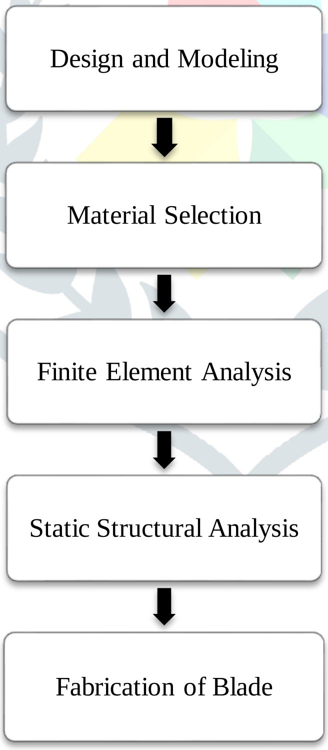
Index Terms - Prosthetic blade, CatiaV5, ANSYS, Fiber reinforced Composite Materials, 3D – printer.

I. INTRODUCTION

Prosthesis is an artificial limb worn by a person who has either undergone a limb amputation or has been born with an absent or deficient limb or limb was lost by an accident. These devices are particularly popular among athletes, especially those who participate in running and other high-impact sports. Many amputations that lead to the need for prosthetic running blades are the result of accidents, such as car crashes, workplace accidents, or other traumatic injuries. In some cases, amputations may also be necessary as a result of medical conditions such as cancer, infection, or peripheral artery disease. Furthermore, a study conducted by Hafner et al. [1] investigated the impact of prosthetic running blades on the quality of life of individuals with lower limb amputations. The study found that using prosthetic running blades led to a significant improvement in the physical and psychosocial aspects of the participants' quality of life. The running blade prosthesis is a type of prosthetic limb designed specifically for athletes and individuals with lower limb amputations who want to engage in running and other high-impact activities. The blade is attached to a socket that fits onto the residual limb, with adjustable straps and to secure the prosthetic to the user's body. This type of prosthesis has become increasingly popular for athletes, especially in track and field, and has enabled many people with lower limb amputations to compete in sports at a high level. Hafner, et al., [2] In the midmost-1980s, the main inventions of the design initially used for entertainment purposes and subsequently used for competition. The design of wound brace for arthropods was developed, which is famous as Terry Fox design, and used the design of a spiral coil spring, Diangelo, et al.,[3] Later, significant progress was made for amputation of the part above the knee and the part below the knee, when Van Phyllis conceived Flex feet in 1987, Hafner, et al.,[4] This is the basic design of current compensation technology for the return of energy in the running sprint. The Flex-foot design includes elastic carbon fibre leg and foot springs, a profile usually "c" or "j".The design and materials used in running blade prostheses have evolved over time, with current research and development focused on fabrication and material properties. These devices typically consist of a curved blade made of carbon fibre or other lightweight materials, which is attached to a socket that fits securely onto the amputee's residual limb. Hayder Kareem Talla et, al [5] The current study concentrated on the production and manufacturing characteristics of a sample athletic prosthetic foot produced from composite materials based on a poly methyl methacrylate resin (PMMA) reinforced with various fibres (Perlon, Carbon fibre, and Glass fibre). In order to explore the impact of deformation and stored energy on the functionality of the sports prosthetic foot, a model of an athletic prosthetic is built using the finite element method (ANSYS-19R) and boundary conditions are applied. Later Mosfequr Rahman et al. [6] focused on the high performance of prosthesis running foot manufactured from carbon fibers that have more advantages than their metal counterparts, they are lighter and have the ability to hold a significant amount of strain energy, finite element analysis technique was used to analyze the prosthetic running foot which known as the blade. Mohsin N. Hamzah et al. [7] manufactured two samples of APF (C-type, cheetah type) and compared between them. Glass fiber with unsaturated polyester the materials have been used in manufacturing. The foot subjected to (load deflection test). The result shows that cheetah blade best from C-type blade. In this paper, a practical and theoretical comparison was made between two feet manufactured from two different materials. 3D imaging and additive manufacturing, commonly referred to as "3D printing", are critical enablers for this study. AM enables complex geometries that are impossible to produce through traditional manufacturing techniques with the added benefit of quicker design and production times. The complexity and customization of parts do not increase processing time or cost and it takes to print a custom prosthetic is significantly reduced when compared with conventional manufacturing methods such as casting. In 3D printing of fibre-reinforced polymer composites have attracted attention due to the wide range of applications in automotive, aerospace, construction, etc. Among various types of polymer composites, nylon reinforced with carbon fiber is among the most popular and commonly used composite materials with a wide range of applications. Barrios et al. [8] developed a 3D printed prosthetic running blade with a semi-elliptical blade design. The blade was made of carbon fiber reinforced with nylon, and the results showed that the 3D printed blade was able to provide sufficient support and stability for amputee athletes during running. Another study by Huang et al. [9] used a 3D printing technique called Selective Laser Sintering (SLS) to produce a prosthetic running blade. The blade was made of nylon powder and was tested on a treadmill. The results showed that the 3D printed blade was able to reduce the loading rate on the amputee's residual limb during running. Later Vaish et al. [10] used a multi-material 3D printing technique to develop a prosthetic running blade. The blade was made of two materials; a rigid material for the blade and a soft material for the foot. The results showed that the 3D printed blade was able to provide shock absorption during running, thereby reducing the risk of injury. Ansys can also be used to evaluate the effect of different materials and manufacturing processes on the performance of a prosthetic running blade. When it comes to prosthetic running blades, Ansys can be used to evaluate the performance of different design configurations, materials, and manufacturing processes. This can lead to faster development cycles, reduced costs, and improved performance and safety of prosthetic running blades for athletes and amputees. Mosfequr Rahman et, al [11] In this study, prosthetic racing legs known as blades were analyzed using finite element analysis technique. Performance improvements of these blades were sought by creating mechanical models of the current Ossur products using the finite element analysis software ANSYS and incorporating better performing composite materials into the mechanical simulations. Two different composite materials have taken in consideration by which the legs are created from; these are thermoplastic values for polyethylene epoxy and Vinyl ester. The use of a new composite material reduces the strain in each of the existing blade geometries, and it permits fewer layers of carbon fiber to be required in the construction of these running blades, which reduces the weight of each leg.

Overall, the development of prosthetic running blades has been a significant advancement in the field of prosthetics, allowing individuals with lower limb amputations to participate in high-impact activities and achieve comparable performance to able-bodied individuals. However, the controversy surrounding the use of prosthetic running blades in sports competitions highlights the need for further research and discussion in this area.

II. METHODOLOGY



a) Design of blade:

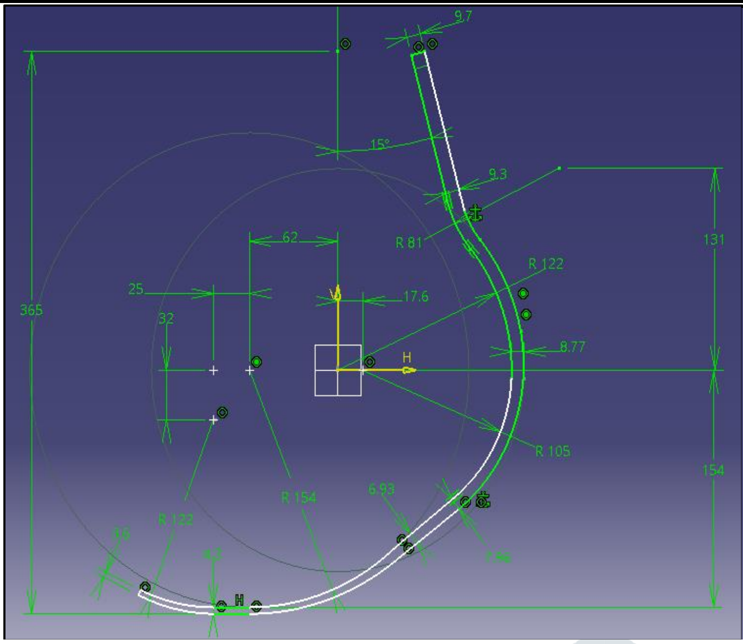


Fig 1. 2D Image of prosthetic runner blade

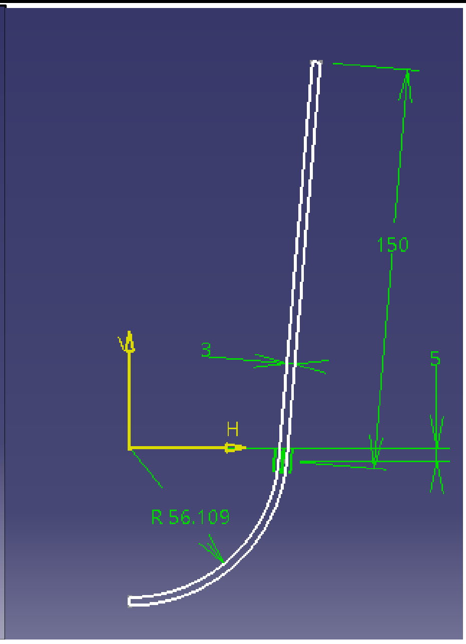


Fig 2. 2D Imageof socket

b) Blade Modelling:

- Create a new part document in CATIA.
- Sketch the rough shape of the blade using the Sketcher tool, and use the Profile and Operation tools to create the basic blade shape.
- Use the Generative Shape Design tool to refine the blade shape by adding details such as curves and fillets.
- Add additional features such as bolt holes and mounting points as necessary.
- Use the Assembly Design tool to create an assembly of the blade with other components such as the foot and the attachment mechanism.
- The actual vision of the manufactured blades is aided by 3D modeling.

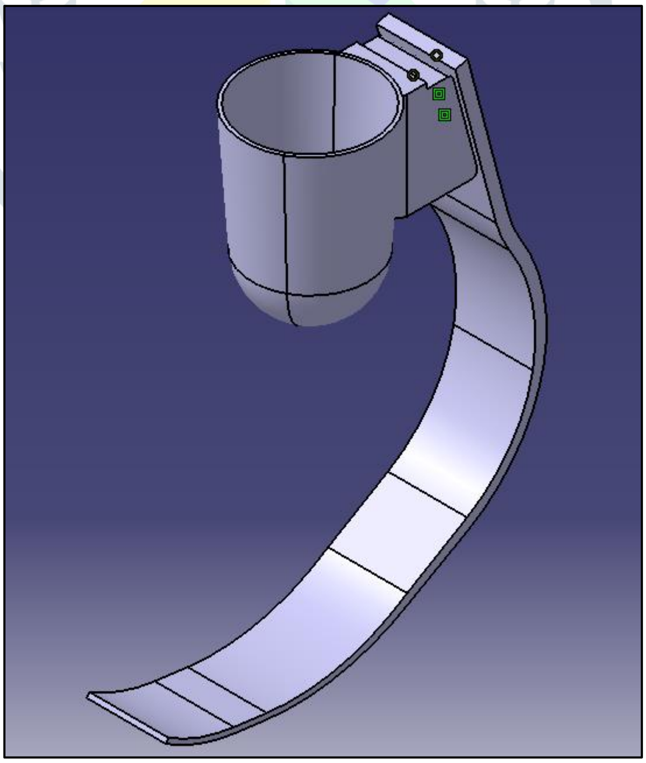


Fig 3. 3D View of prosthetic runner blade

c) Materials and methods:

The material selection of a prosthetic running blade is a crucial aspect to ensure the blade's performance and durability. Typically, prosthetic running blades are made from lightweight and high-strength materials that can withstand the high impact forces generated during running and jumping.

The most common material used for prosthetic running blades is carbon fiber composites. Carbon fiber composites offer high strength-to-weight ratios and excellent fatigue resistance, which makes them ideal for prosthetic running blades. Additionally, carbon fiber composites have a high degree of stiffness, which allows the blade to store and release energy efficiently during running and jumping.

Here we are comparing between two materials like Carbon fiber reinforced polymer (CFRP) and carbon fiber reinforced nylon (CFRN) are two different materials that are commonly used in manufacturing high-performance products. While both materials use carbon fibers to reinforce the polymer matrix, there are some key differences between the two materials.

Material Composition:

CFRP is made up of carbon fibers that are embedded in a polymer matrix, which is usually a type of epoxy resin. The carbon fibers provide strength and stiffness, while the polymer matrix serves to hold the fibers together and protect them from damage. In contrast, CFRN is made up of carbon fibers that are embedded in a nylon polymer matrix. The nylon provides good mechanical properties and can withstand high stress, while the carbon fibres provide added stiffness and strength.

Properties:

CFRP and CFRN have different mechanical properties due to the different polymer matrices used. CFRP is known for its high strength, stiffness, and low weight. It has a high resistance to fatigue, making it suitable for applications such as aerospace and motorsports. CFRN, on the other hand, has good mechanical properties such as high stress resistance, toughness, and high impact resistance. It is commonly used in applications such as sports equipment and prosthetics.

Table 1: Material 1 Properties CFRP

S.NO	Property	Value	Units
1	Density	1.6	g cm^-3
2	Coefficient of Thermal Expansion	1.2 E-05	C^-1
3	Reference Temperature	22	˚C
4	Young's Modules	70000	MPa
5	Poisson Ration	0.1	
6	Bulk Modulus	29167	MPa
7	Shear Modulus	3.1818 E10	MPa

Table 2: Material 2 Properties CFRN

S.NO	Property	Value	Units
1	Density	1.5	g cm^-3
2	Coefficient of Thermal Expansion	1.135 E-05	C^-1
3	Reference Temperature	25	˚C
4	Young's Modules	55000	MPa
5	Poisson Ration	0.35	
6	Bulk Modulus	2.5	GPa
7	Shear Modulus	2.8747 E10	MPa

d) Analysis

Static structural analysis is a method used in engineering to determine the stresses, strains, and displacements in a structure under external loads. This type of analysis is typically used to design and optimize the performance of structures.

In static structural analysis, the structure is modeled as a set of interconnected elements, each with its own material properties and physical characteristics. The loads acting on the structure, such as forces and moments, are applied to the model, and the resulting stresses and strains in each element are calculated using mathematical equations based on the laws of mechanics. The results of static structural analysis can be used to ensure that a structure is strong enough to withstand the expected loads and to identify any areas of the structure that may need reinforcement. It can also be used to optimize the design of the structure by identifying areas where material can be removed or redistributed without compromising its strength.

Finite Element Analysis (FEA) can be used to analyze the performance of prosthetic running blades. The following steps can be followed:

- Geometry Creation: The first step is to create a 3D CAD model of the prosthetic running blade. This model should be detailed enough to capture all the important features and design aspects.

- Material Properties: The material properties of the blade need to be defined in order to carry out FEA. For prosthetic running blades, the most common materials are carbon fibre composites, which have high strength and stiffness-to-weight ratios.

- Boundary Conditions: Boundary conditions need to be defined to simulate the loading conditions that the blade will experience during running. This can include the weight of the runner, the impact forces generated during running, and the bending and torsion of the blade.

- Mesh Generation: A finite element mesh needs to be generated on the CAD model. The mesh should be fine enough to accurately capture the stress, strain distribution and total deformation in the blade.

- Analysis Setup: The FEA analysis should be set up to define the analysis type, material properties, and boundary conditions.

- Results Analysis: The FEA software will generate results such as stress and strain distribution, deformation, and displacement. These results can be analysed to determine the blade's performance and whether any design changes are necessary.

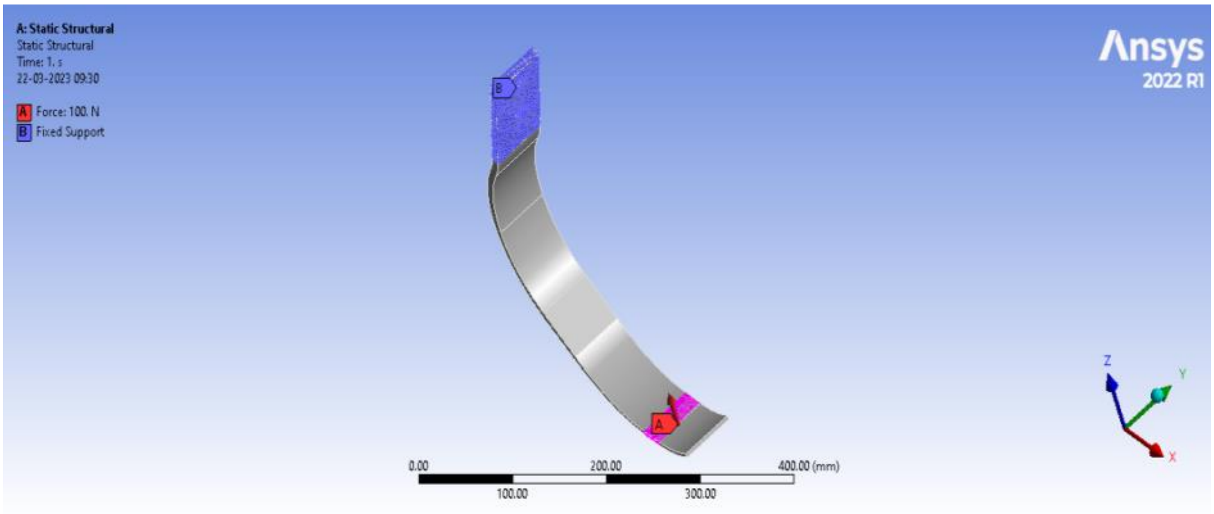


Fig 4. Boundary conditions

Meshing:

In the analysis of a prosthetic running blade, meshing plays a critical role in accurately modeling the behavior of the blade under various loads and conditions. Meshing refers to the process of dividing the complex geometry of the blade into a collection of simple, interconnected elements as it can greatly affect the accuracy and efficiency of the results.

In general, a finer mesh will provide more accurate results and in this mesh work the numbers of nodes 38348 and the elements 22790 and finer mesh will generally provide more accurate results, but will also require more computational resources and longer processing times.

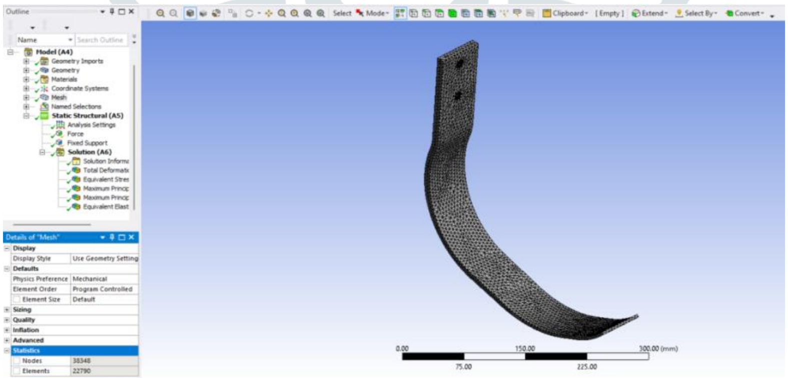
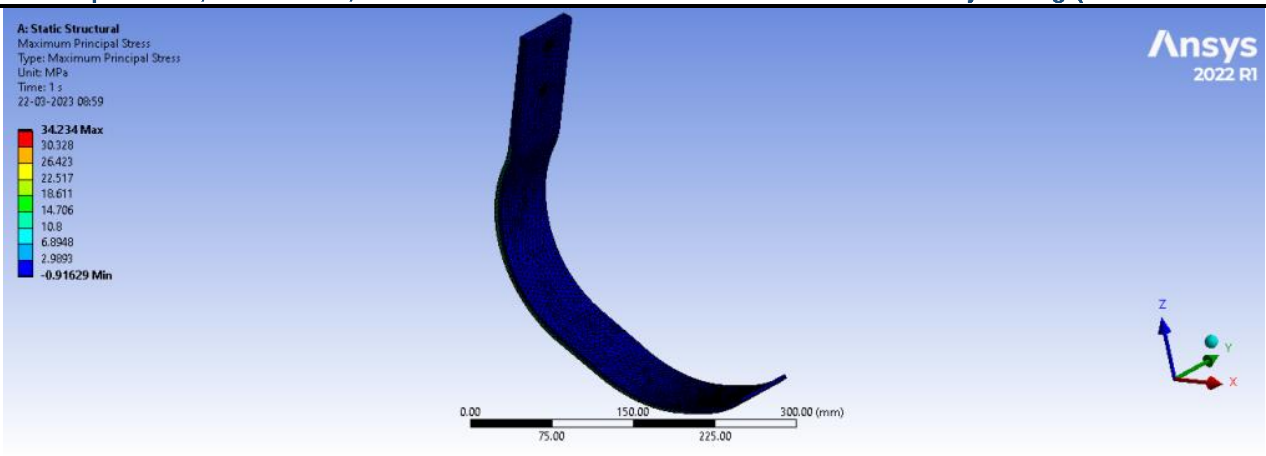
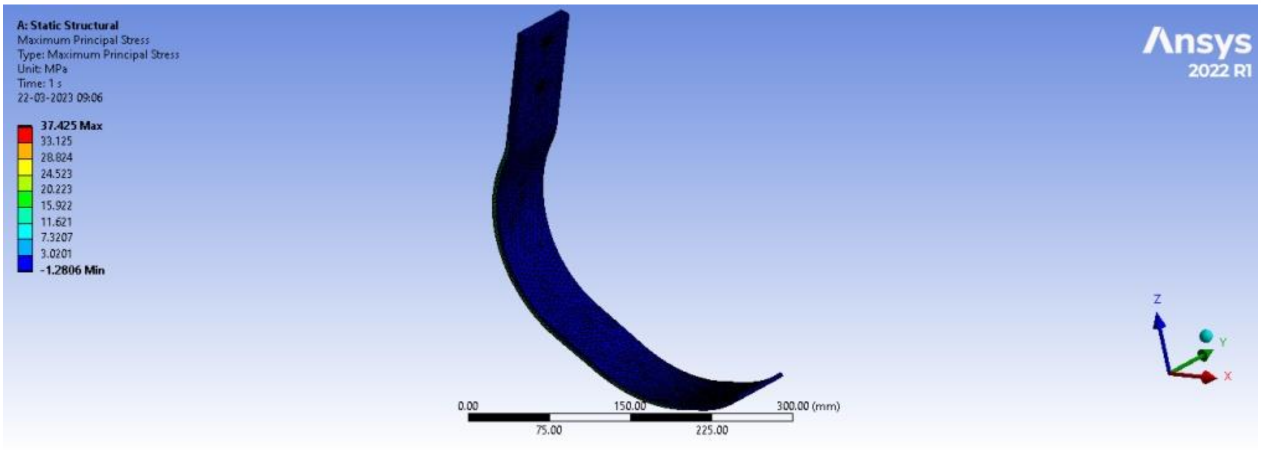


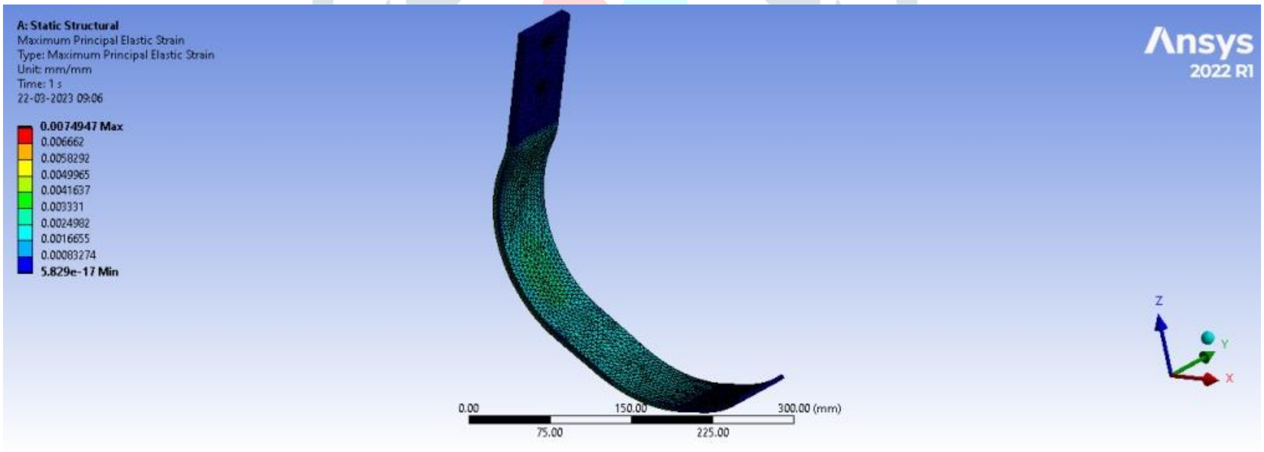
Fig 5. Mesh sizing

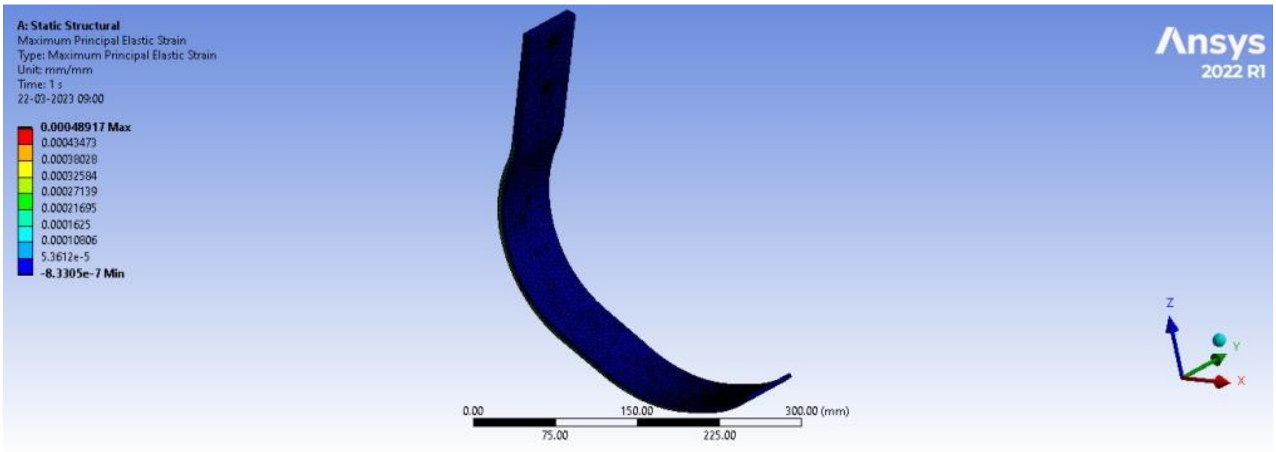
a) Maximum principal str



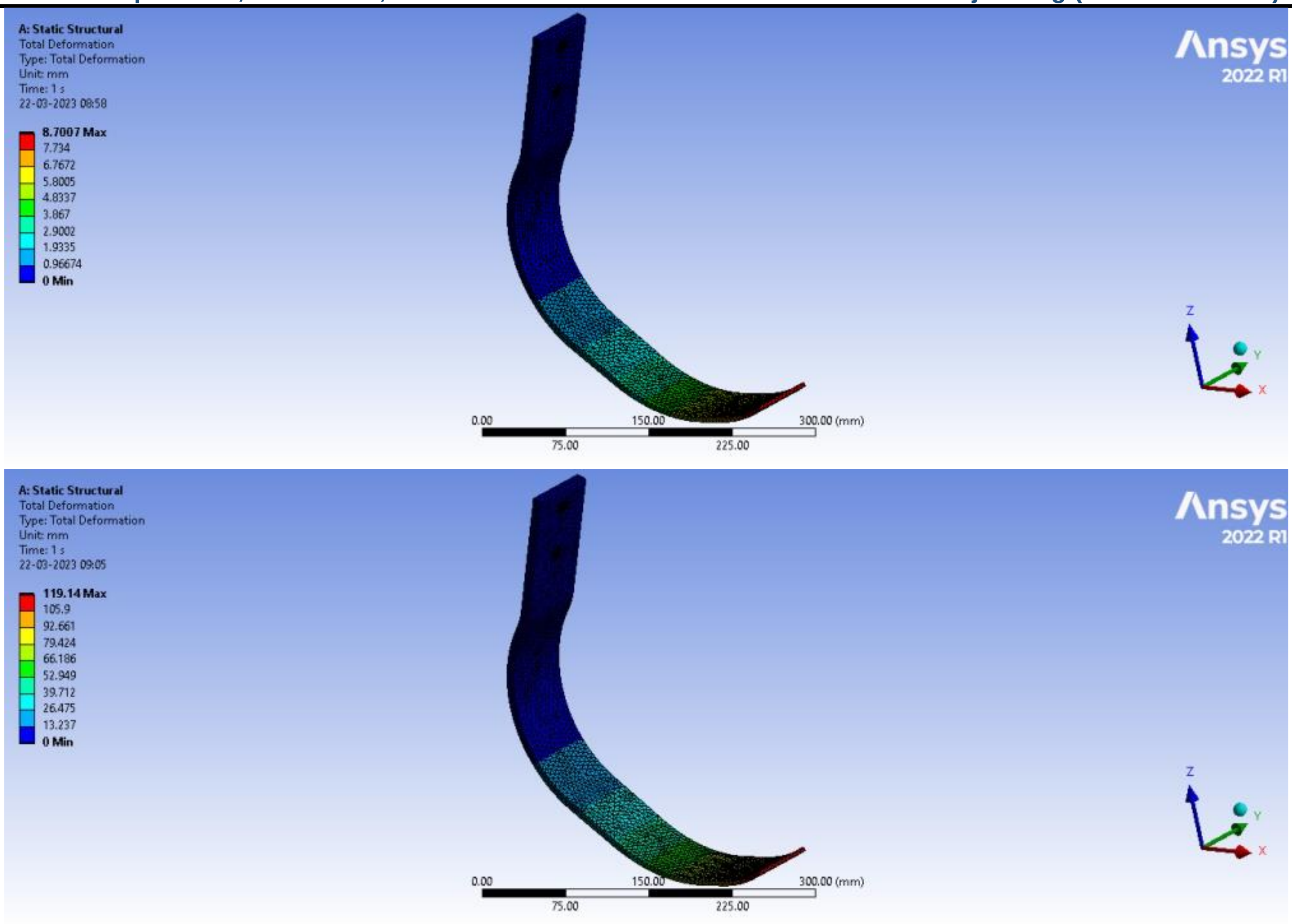


b) Maximum principal strain

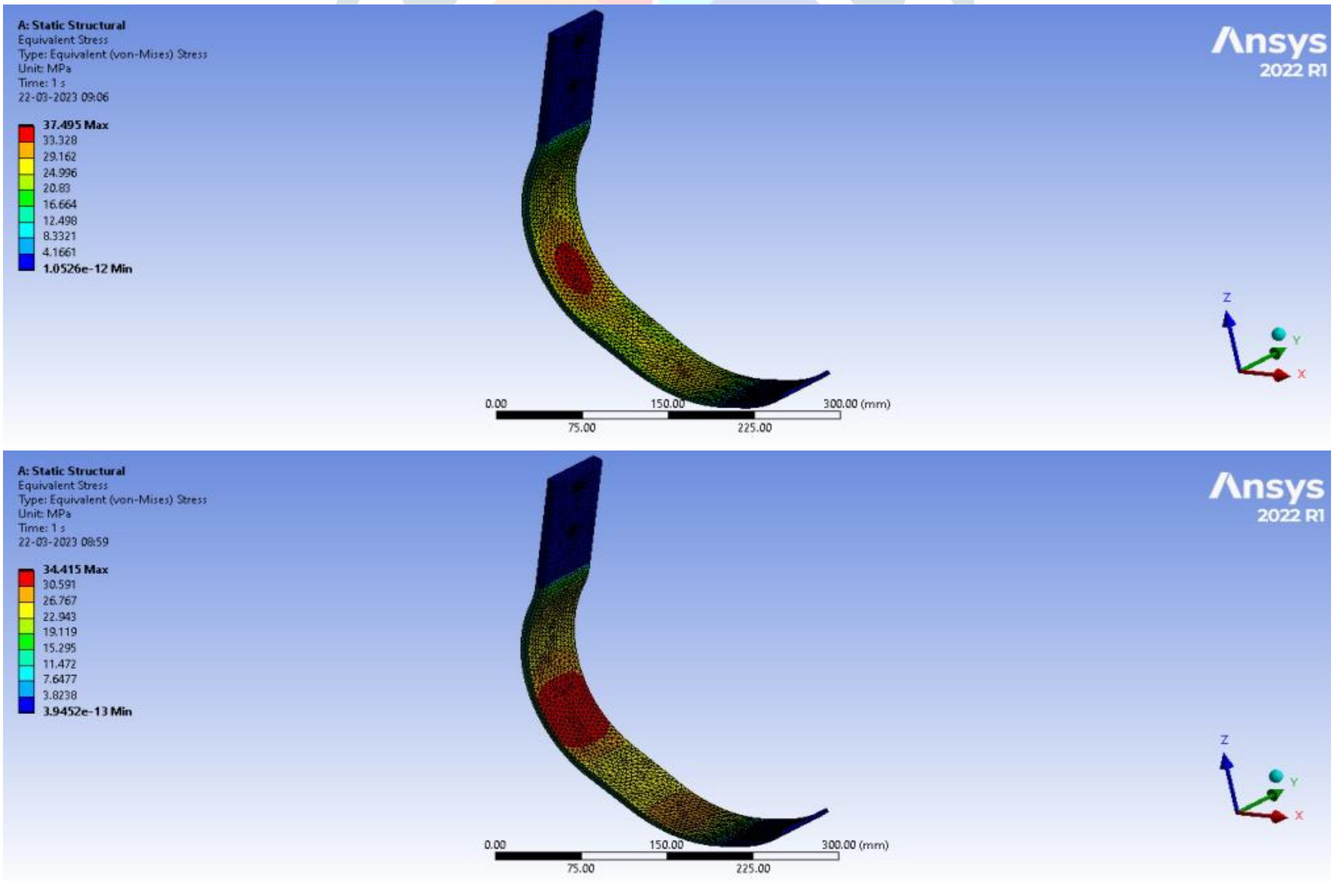




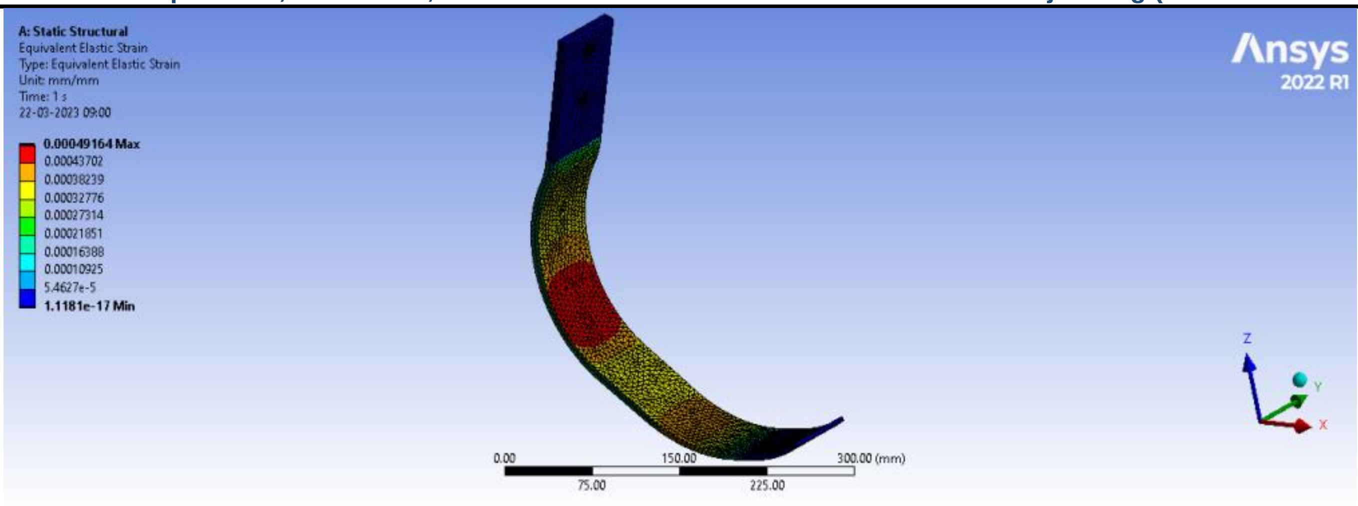
c) Total deformation

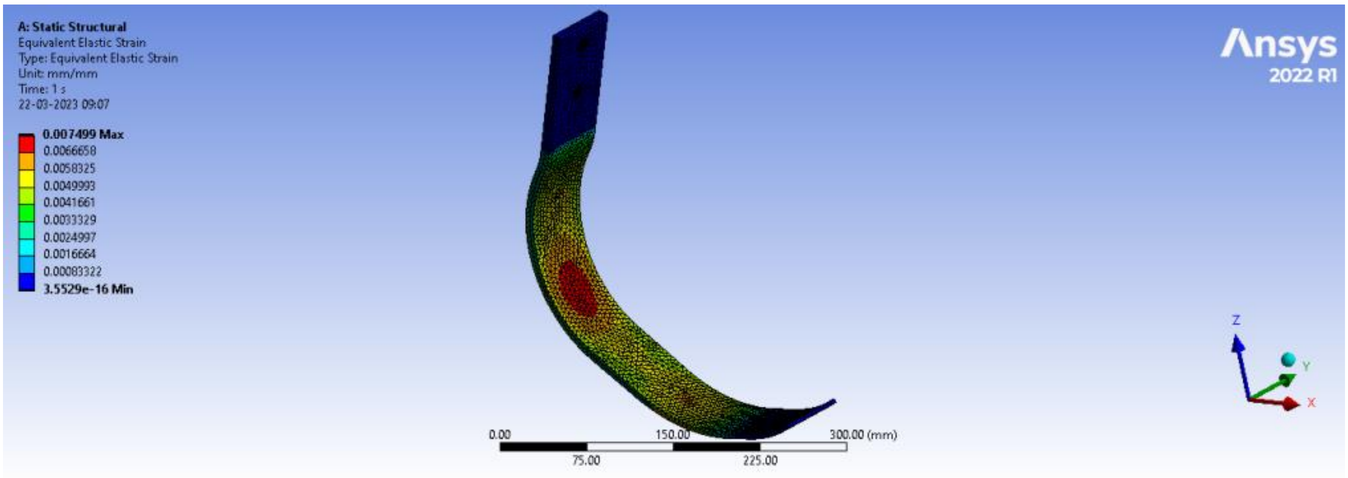


d) Equivalent stress



e) Equivalent elastic strain





e) Fabrication:

Prosthetic running blade manufactured using 3D printing technology.

The basic working principle of FDM is similar to other AM processes where a layer of material deposited over the heat bed in desired pattern, lay one over the other as per the instruction given by the slicer software. In addition to thermoplastic, the printer also extrudes support material to give support for overhangs and bridges wherever the support is needed. The extruder increases the temperature to the melting point of the loaded thermoplastic and extrudes the fused material through the nozzle on the heated printing bed. FDM printers utilize the most common materials such as ABS (Acrylonitrile Butadiene Styrene), PLA (Poly lactic Acid), PETG and Nylon.

- 3D printing filament or resin (typically a strong, durable material such as carbon fibre reinforced nylon)
- Prosthetic blade components (such as a socket, pylon, and foot plate)
- Adhesives (such as epoxy)

The following steps are involved to fabricate the prosthetic running blade:

- **Initial Design:** The first step is to design the prosthetic running blade using Computer-Aided Three Dimensional Interactive Application (CATIA) software. This design will serve as a blueprint for the 3D printer.
- **Selection of Printing Material:** Depending on the specific requirements of the prosthetic blade, the printing material is chosen. Most commonly used materials for prosthetic running blades are Nylon, Carbon Fibre.
- **3D Printing:** The CAD design is loaded into a 3D printer, which prints the prosthetic blade layer by layer. The 3D printing process can take several hours to complete, depending on the complexity of the design and the size of the blade.
- **Finishing Touches:** Once the printing process is complete, the prosthetic running blade is removed from the printer and any excess material is removed. The blade may require some additional finishing touches, such as sanding or polishing.
- **Fitting and Testing:** The final step is to fit the prosthetic blade to the amputee's residual limb and make any necessary adjustments. The blade is then tested for functionality and comfort.

It's worth noting that the above steps are a general guide and may vary depending on the specific 3D printing technology and materials used. Additionally, the design and manufacturing process may require the involvement of a team of specialists, including prosthetists, orthopedic surgeons, and engineers, to ensure that the prosthetic blade meets the unique needs of the amputee.

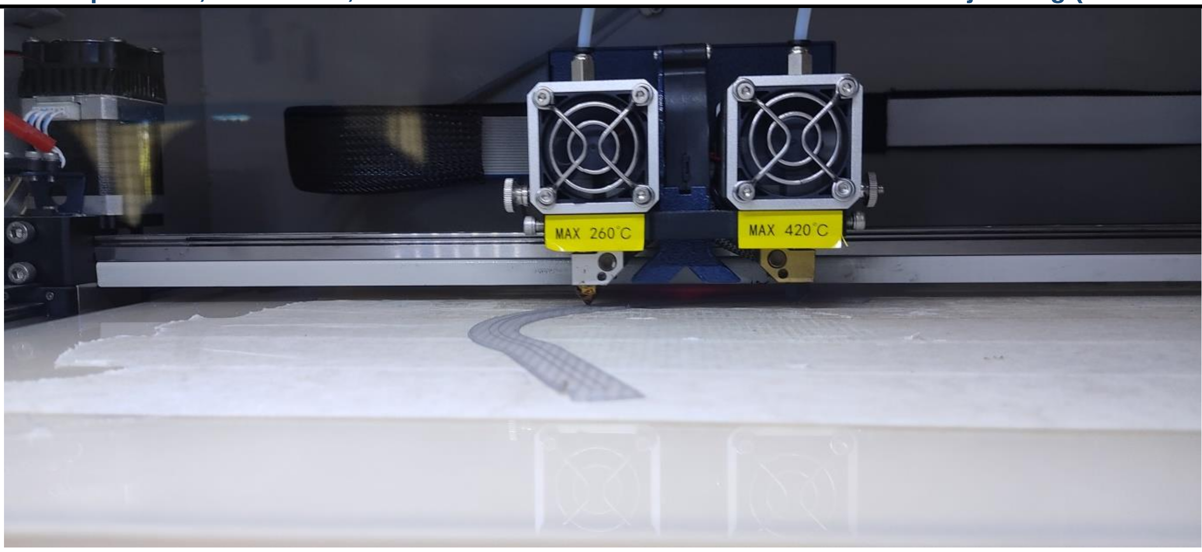


Fig 6.Printing Process

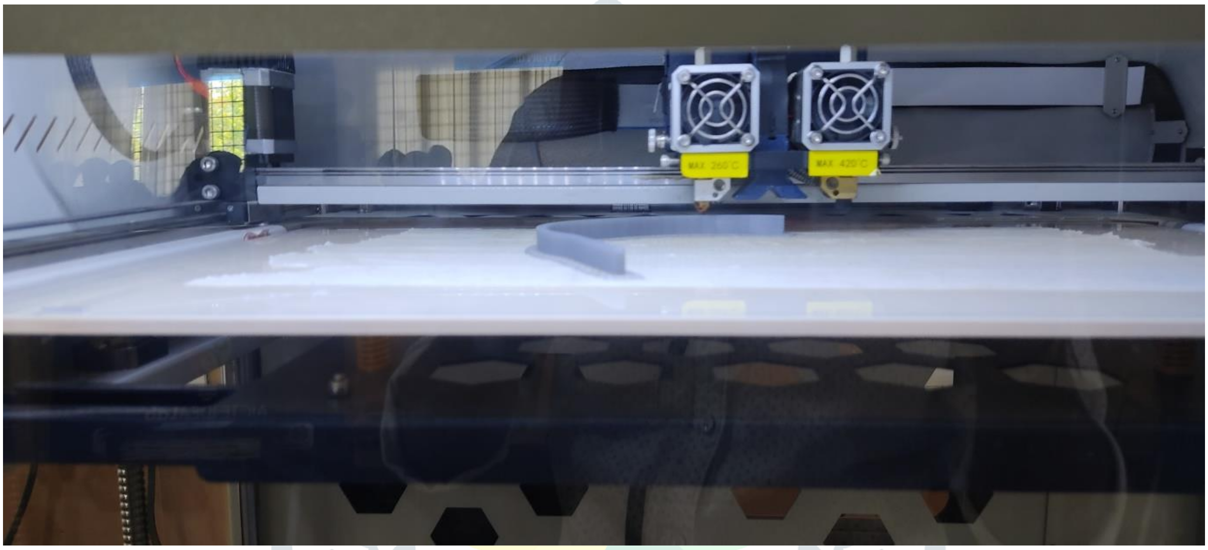


Fig 6.Layer by Layer

Fig 6.Final Product

III. RESULTS AND DIS

Prosthetic running blades are devices that are designed to provide athletes with lower limb amputations with the ability to run and participate in various sports. Two commonly used materials for the construction of prosthetic running blades are Carbon Fiber Reinforced Polymer (CFRP) and Carbon Fiber Reinforced Nylon (CFRN). However, this paper shows that the CFRN blade had a lower peak ground reaction force than the CFRP blade. This means that the CFRN blade was able to reduce the impact forces on the athlete's residual limb, potentially reducing the risk of injury. And coming to results the maximum stress is more for nylon material as per properties compared to polymer material.

Overall, the results suggest that both CFRP and CFRN are variable materials for the construction of prosthetic running blades, and the choice of material may depend on the specific needs and preferences of the athlete. CFRP may be preferred for athletes who prioritize performance and speed, while CFRN may be preferred for athletes who prioritize comfort and safety.

	Max	Min
Maximum principal stress	37.42 MPa	-1.2806 MPa
Maximum principal strain	0.0004891 mm/mm	5.829e-17 mm/mm
Equivalent stress	37.495 MPa	1.0526e-12 MPa
Equivalent strain	0.007499 mm/mm	3.5529e-16mm/mm
Total deformation	119.1 mm	0 mm

	Max	Min
Maximum principal stress	34.23 MPa	-0.91629 MPa
Maximum principal strain	0.00749 mm/mm	-8.3305e-7 mm/mm
Equivalent stress	34.41 MPa	3.9452e-13 MPa
Equivalent strain	0.0004916 mm/mm	1.1181e-17 mm/mm
Total deformation	8.7007 mm	0 mm

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