iJRASET
International Journal For Research in Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH
IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 11 Issue: I Month of publication: January 2023

DOI: https://doi.org/10.22214/ijraset.2023.48876

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 11 Issue I Jan 2023- Available at www.ijraset.com

Modelling and Analysis of a Prosthetic Runner Blade

P. Hari Krishna[1], P. Pardha Sai[2], K. Chandu[3], I. Brahmaiah[4], T. Haritha[5]
[1, 2, 3, 4]UG Students, [5]Associate Professor, Department of Mechanical Engineering, NRI Institute of Technology, Agiripalli, Eluru District, A.P, India, Pin: 521212

Abstract: Prosthetic leg/ Runner blade design is very crucial, which uses the principles of mechanical engineering to achieve the best outcomes. In general, these are useful for leg amputated individuals to replace the below-knee portion with a prosthetic leg. Its function is to assist make up for the user's compromised physiology by imitating the anatomical foot/ankle joint action of physically fit persons.

Very limited study has been carried out on the motion investigations, material bio compatibility, stress concentrations and economic aspects. This project aims to make an attempt to study aspects of stress, stain variations using different materials. Here, a 3D model is generated using CATIA V5 and then imported to ANSYS R15 for analysis. Weight reduction, cost effectiveness with good structural stability are the issues planned to be addressed using this project.

Keywords: Prosthetic leg, amputation, CATIA V5, ANSYS.

I. INTRODUCTION

Many people throughout history have worked to support folks who have lost limbs so they can live more fulfilling lives. Based on the scant information we have found, the history of prosthetics predates the development of writing. As technology evolved, it became possible to replace a simple artificial leg made of wood or iron with more sophisticated devices that were closer to mimicking organic function. The advancements of modern prostheses that we enjoy would not be possible without the forerunners. The history of the prosthetic limb from prehistoric times to the present is celebrated in this article. There may not be many surviving instances of prosthetic legs from antiquity.

Many of them were composed of perishable materials, and limb amputations back then had an astonishingly high mortality rate. What little evidence we do have, however, suggests that our earliest forebears had a common desire to give the human body form and function.

In order to create a secure connection between the prosthetic and residual limbs, suspension mechanisms are crucial components of the lower limb prosthesis. Silicone liners are the primary suspension system in many modern suspension systems. Because these devices offer a fit that is identical to the residual limb, superior suspension, increased aesthetics, and improved function, lower limb amputees have expressed hopes for these silicone liners. A nice overall experience is provided by prosthetic devices that combine silicone liners and suspension components. Numerous silicone suspensions are currently in use, either by a distal single pin, a circumferential seal, or seals that create vacuum on the socket wall, linked to the hard socket. Prosthetic hard sockets used for silicone suspension need to be smaller than necessary to guarantee a total-surface bearing fit.A system that can be inside or outside the human body and covers the missing part or structure is called a prosthesis. The components of an artificial body created for amputees are known as prostheses.

A certain kind of amputee has affected a sizable number of people. The tactic makes an effort to focus on them. Among the amputations are the arm, knee, arm, foot, and hand. Our goal is to address this problem with an affordable, adaptable solution that can be customised to the demands of the client. The development and production of 3D-printed prosthetic lower limbs is the aim of this research. The use of effective materials that are also lightweight and affordable is another goal of this programme. In contrast, the use of earlier technology would continue. The "Prosthetic Lower Limb" concept, which consists of various components, is the foundation of the project.

The main parts of a prosthetic are the hips, elbows, feet, suspension, liner, connector, and construction materials. Around the world, initiatives have been made to boost leg work and increase prosthetic efficiency. We concentrate on the prosthetic foot in particular. The proposed methodology is predicated on the simulation and manufacture of the patient's residual extremities. The creation of the prosthetic foot can be divided into three main phases: specification, validation, and development.

II. LITERATURE REVIEW

Yasser Alizadeh et, al [1] In this article, they build composite running blades for athletes. The implementation of explicit dynamics analysis within Abaqus CAE, which models the high loading and impact circumstances when such a prosthetic is utilised by an athlete, is the main point of interest. Step-by-step explanations and reports are provided for material selection, static, impact, and explicit dynamic analyses as well as the outcomes. This design achieves the design objectives with all the presumptions specified before. First off, for the composite design, which is at 30% of the ultimate tensile strength of the composite materials, the maximum Von- mises in the blade is always less than 465MPa.

Lee Nolan et, al [2] The current state of knowledge regarding carbon fibre prosthesis and its impact on transtibial amputees' running style will be discussed in this review. Performance in sports by amputees has improved significantly over the past 20 years, in part due to the invention of carbon fibre prosthetics. As the margins between winning and losing narrow, sportsmen depend more and more on prosthetic limb technology to provide them an advantage over rivals and break previous records.

Saleel Hussein Abood et, al [3] This study compared two Flex-Foot Cheetah samples made of two different materials (carbon and glass) and polyester in order to determine which foot performed the best when running at the level of a professional athlete. The greatest principal stress, maximum principal elastic strain, strain energy, and finally the total deformation of the blade for both feet were computed throughout the numerical analysis. The load-deflection test was carried out for the foot in experimental work to determine the bending, and the results were extremely close to the numerical result.

Dalvi Anuj M et, al [4] During the first point of contact during the stance phase, the lower limb's muscles and joints absorb energy. Later on, during the forward and upward motion of the stance phase, they supply propulsion. A continuous J-shaped structure without an articulating joint like the ankle characterises the construction of PRB, which are made of several types of composite material. Lower limb prostheses' performance evaluation criteria are still being formally established. Experiments are carried out to examine the linearity, stiffness, and evaluation of feet-based energy return prosthesis technology, which is generally employed for elite level high speed running. Initial research has led to the conclusion that energy return prostheses for athletes who are missing a lower leg should not be specified or regulated using static load testing.

Hayder Kareem Talla et, al [5] This study looks at how prosthetic limbs are used, particularly the sports prosthetic foot. The current study concentrated on the production and manufacturing characteristics of a sample athletic prosthetic foot produced from composite materials based on a polymethyl methacrylate resin (PMMA) reinforced with various fibres (Perlon, Carbon fiber, and Glass fiber). 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.

Wafa Ouarhim et, al [6] This study's goal was to investigate the effects of various deformations (such as buckling, bending, and relaxation) on the characteristics of laminated composite materials using polyester as the matrix and glass fibre in two forms—woven fabric and chopped-strand mat. The specimens have varying numbers of plies but were created with the same thickness. In order to obtain a third series, a thin gelcoat made of clay particles was also applied to the chopped strand mat samples. The findings demonstrated that, even when utilising the same thickness, the number of layers affects the mechanical properties, particularly in terms of bending and buckling. Additionally, a sports application for a leg prosthesis is offered as an applied inquiry, which is the main goal of this work. Three distinct "Flex-foot Cheetah" running blades were created to be mathematically described using ANSYS software to mimic real-world situations. The produced blade was tested in quasi-static and dynamic compression, and the results showed that the relaxation behaviour depends on the structure design and the materials used. The results showed a good agreement between the experimental and numerical values in terms of total displacement, which is around 50 mm.

Mosfequr Rahman et, al [7] 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 Vinylester. 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.

Viswanath Srinivasan et, al [8] The kinetic energy from the user's footsteps is stored as potential energy by the running blades, which works on the same principle as a spring and enables the user to run and leap. Excessive weight, a lack of Indian producers, expensive prices stated by international manufacturers, and a lack of awareness of this technology among the local populace are the main current shortcomings of existing prostheses.

The main goal of the project is to create a cheap composite blade with a distinctive shape that would make it simpler for amputees to walk and run normally. The project's technique comprises selecting an appropriate composite from among glass, carbon, and hybrid fibres through material testing, evaluating the design using finite element analysis (FEA), to create the blades themselves and conduct gait analysis on the users' motion patterns.

Paul delton et, al [9] It is necessary to use a theoretical approach in order to investigate how a prosthesis's size, shape, and stiffness affect sports performance; nevertheless, this calls for a more complicated depiction of the prosthetic than what has previously been used. An athlete with a unilateral transtibial amputation performed six different actions, and the complexity (n-segments; n=2,3,4) needed to replicate the kinematics and kinetics of a prosthetic during those movements was examined using a chain model.

M hamaz et, al [10] According to the current study, the suggested design offered a smooth roll-over form and a good response to energy return needs in ankle-foot prostheses, with the keel and heel design behaving as a non-prismatic cantilever beam. Based on the exact materials utilised, the keel and heel thicknesses need to be optimised. Although insufficient deflection was shown in the vertical loading test, FE analysis showed successful heel and keel deflections. Under a pressure of 300 N, the heel deflected by 29.18 mm, the keel by more than 25 mm, and the deflection under a vertical load of 1,230 N was roughly 8.1 mm. The strain and stress seen in the three tests were within acceptable ranges, and the majority of the energy was absorbed in the ankle component of the prosthesis.

A.S. Dickinson et, al [11] This systematic literature review investigates the state of the art in residual limb finite element analysis published since 2000. The identified studies were grouped into the following categories: (1) residuum-prosthesis interface mechanics; (2) residuum soft tissue internal mechanics; (3) identification of residuum tissue characteristics; (4) proposals for incorporating FEA into the prosthesis fitting process; (5) analysis of the influence of prosthetic componentry concepts to improve load transfer to the residuum, such as the monolimb and structural socket compliance; and (6) analysis of osseo integrated (OI) prostheses.

Johannes Funken et, al [12] This study used a 3D motion capture system and four force plates to assess ground reaction forces (GRFs) and moments acting on the prosthesis blade. A top world level left-sided unilateral amputee athlete ran 30 metres straight and curved, clockwise and anticlockwise. GRFs demonstrate the distinctions between straight and curved running. Results indicate that when running on a curve as opposed to a straight line, a prosthesis' blade is subjected to variable loading. The study provides insight into the mechanics of amputee curve running and may have an impact on the development and design of upcoming generations of prostheses as well as performance diagnostics.

Lara Grobler et, al [13] The purpose of this study was to describe two commercially available running-specific prostheses. study plan: In an experimental setting, the running-specific prostheses were tested without the interference of changes in athlete performance. All masses lost showed comparable trends across models and categories within the outcome variables; therefore, for the sake of simplicity, only the 38-kg results will be covered in depth.

Carolin Curtze et, al [14] We identified the roll-over traits of a wide range of prosthetic feet and looked at how different types of shoes affected these traits. An contraption resembling an inverted pendulum was used to simulate the body weight of a person rolling over on a prosthetic foot. The effective radius of curvature, the centre of pressure's forward motion, and the instantaneous radius of curvature of the prosthetic feet were all measured. We conclude by talking about how these variables relate to amputee gait.

C.T. Barnett et, al [15] The current study examines the effects of increasing RSP stiffness on limb stiffness, running efficiency, and related joint kinematics in people who have undergone unilateral transtibial amputations. Methods: Eight males with unilateral transtibial amputations ran along a 15-meter runway at self-selected submaximal speeds in three RSP stiffness conditions: recommended habitual stiffness (HAB), stiffness categories above (+1), and stiffness categories below (-1) the HAB after a 10-minute familiarisation period. For each limb, joint/RSP work, limb stiffness, contact time, and stance-phase centre of mass velocity were estimated across RSP stiffness conditions.

Cem Guzelbulut et, al [16] The simulation's objective is to watch athletes' contact behaviour in various locations throughout a prosthesis' contact phase. Two distinct behaviours are seen when the prosthesis makes contact with the ground: compression happens at a greater contact zone, whereas release occurs at a smaller contact region (almost only the tip of the prosthesis). Different force displacement characteristics, such as second order and linear characteristics, are produced, and the prosthesis' design is modified to change how the initial region behaves. The contact angle (angle of attack) and stiffness of a prosthesis affect the releasing phase of the prosthesis. A non-linear spring-mass system is created by combining the two contact phases. Through the non-linear mass-spring system, ground reaction forces are computed.

The significance of the contacting area, the length of the moment arm during contact, and the impact of each kind of force-displacement characteristic on performance are finally covered.

Mosfequr Rahman et, al [17] In this work, blades—prosthetic racing legs—were examined using the finite element analysis method. The present Ossur products were mechanically modelled using the finite element analysis programme ANSYS in order to increase the performance of these blades. Additionally, better performing composite materials were incorporated into the mechanical simulations. Two different composite materials—thermoplastic values for polyethylene epoxy and vinyl ester—have been taken into account when designing the legs. The introduction of a novel composite material lowers the strain in each of the existing blade designs and enables the running blades to be built with fewer layers of carbon fibre, hence lowering the weight of each leg.

Abdul Kareem F et, al [18] In this study, the side profiles from a European patent specification were used to estimate the blade dimensions, and the mechanical properties of various layers of composite materials (UHMWPE, carbon, glass fibre, and Perlon) used in the construction of sports prostheses were investigated experimentally, theoretically, and numerically. The results were compared, and the theory of failure was also calculated. The impact of data entered into the ANSYS programme on isotropic or orthotropic materials was also examined.

Johnnidel Tabucol et, al [19] The ESR feet are the prosthetic feet that are most frequently recommended to patients with K3/K4 levels of ambulation. Energy-storing and -releasing is referred to as ESR. Elastic components in composite materials store elastic energy (carbon fibre or glass fiber).

The loads that a healthy human foot experiences and its gait kinematics must be taken into account when developing and optimising the stiffness of ESR feet. The literature approaches for prosthetic foot design are not based on a systematic process, according to the most recent analyses. Following a methodical process and a finite element structural analysis-based methodology, the stiffness of ESR feet is optimised.

Felix Starker et, al [20] The work that follows is a case study on design changes made to a prosthetic foot in order to achieve variable stiffness. Finite element modelling is used to simulate the adjustments in order to meet the goal of a proof-of-concept. A controlled damping component has been incorporated into the design, and it is coupled to a system of springs both in parallel and in series. In order to adjust the device's stiffness under dynamic loading, a large damping constant that approaches force coupling for the specified boundary conditions is applied.

The mechanical test methods used to determine load response in full roll-over of prosthetic feet are simulated using dynamic modelling. The damped effect is justified by the element's activation while the foot is being loaded. It is thought to be vital to quantify the wasted energy in such an element because dampening runs counter to the primary design goals of energy return in prosthetic feet. Our design example demonstrates how adding a damping component with a high damping constant can boost the device's overall rotational stiffness by 50%. The energy dissipation in the active element is roughly 20% of the maximal strain energy given a large enough damping coefficient.

III. METHODOLOGY

The methodology has been divided into two following subdivisions namely, blade modelling, finite element analysis. by using computational methods (CATIA V5 and ANSYS).

A. Blade Modeling

The design was inspired by biological principles. The design was influenced by the kangaroo's foot mechanism. To provide the kangaroo's hop force, stretchy tendons join the muscle to the bone. With each hop and bound, the kangaroo's tendon compression releases, lifting it into the air like a coiled spring. The prosthesis that fails to produce the most thrust with the least amount of effort was designed using the same idea.

The composite prosthesis, which has a bend at the blade's end and is designed using the same principle, The bottom curve, which comes into touch with the socket, receives kinetic energy from the user's steps. Due to ground response, the lower curve produces upward thrust. The heel is raised during this push-off phase, which bends the blade's toe. The virtual tendon winds up as a result of the blade toes bending. All of the joints in the blade are compressed as the heel of the blade is raised higher. The ensuing propulsion phase is aided by this compression. For the foot to propel forward and absorb shock during the gait cycle, toe flexion is essential. modelling entails using the CATIA V5 modelling environment with the precise shape and dimensions to graphically portray the suggested blade design. The actual vision of the manufactured blades is aided by 3D modelling, which also lowers the possibility of manufacturing damaged blades, which would otherwise result in a loss of manufacturing costs.

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 11 Issue I Jan 2023- Available at www.ijraset.com

B. Static structural analysis

In FEA, a design is fed into a computer model and then examined for particular outcomes. Ansys is the programme used for static FEA. Importing models, assigning materials, meshing, configuring the analysis, and producing results are all aspects of analyses. To create nodes and elements during meshing, default element size and programme controlled element order are employed. The ANSYS material library declares the mechanical testing properties. The lower curvature's bottom surface serves as a fixed support for the loading procedure as part of the boundary condition. Over the top face of the upper blade curve, force is applied for one second. Total deformation, Stress, and Strain Energy are the results. Red colour denotes the region with the highest parameter values, and blue, the opposite.

1) *Stress:* In terms of physics, strain is the measurement of the material's deformation, whereas stress expresses the internal pressures exerted on neighbouring particles of a continuous substance
2) *Strain:* Calculation of geometric deformation that explains how far a material body is moved in relation to other particles. Strain may be produced inside a material by a variety of mechanisms, such as stress caused by external forces acting on the surface or the bulk (such as gravity) (like contact forces, external pressure, or friction). Every pressure applied to a rigid material results in an internal elastic stress that acts as a response force for a spring, helping to restore the material to its initial non-deformed state.
3) *Deformation:* Total deformation is the process by which a body is changed from a reference configuration to a different configuration using continuum mechanics.

IV. MODELING AND ANALYSIS

A. Modeling

Using CATIA for the model

1) Open CATIA V5 software.
2) Start-mechanical design-part design-enter the name.
3) Select the x-y plane.
4) Start with the top portion of the prosthetic runner blade.
5) Go with profile-line-draw a vertical line of 781mm.
6) profile bar-circle-draw the circle with a radius of 1100mm.
7) Go on constraints bar-select constraint defined and then select the planes circle and the vertical line and then dialogue will open click on the tangential, then the circle andthe line will be come in contact in tangentially.
8) Again draw circle with a radius of 730mm, constraint the two circles tangentially.
9) Remove the unwanted lines, take the three point curve and continue with the second
10) Take the two point curve with the radiuses of the 2500 and 1000.
11) Constraint the curve and the R730 circle tangentially.
12) Then the both circle and the curve would be the tangentially constrained.
13) Give the 40mm line vertically with the curve and again take the three point curve witha radiuses of 2550, 1500, 1500.
14) By the curve has drawn, after that take circle with a radius of 650mm.
15) Go to the constraints and select the objects curve and R650 circle, the circle and curve constrained tangentially.
16) Draw the vertical line with a length of 781, after join the two vertical lines.
17) Finally the sketch was completed, sketch shown in below fig 1.

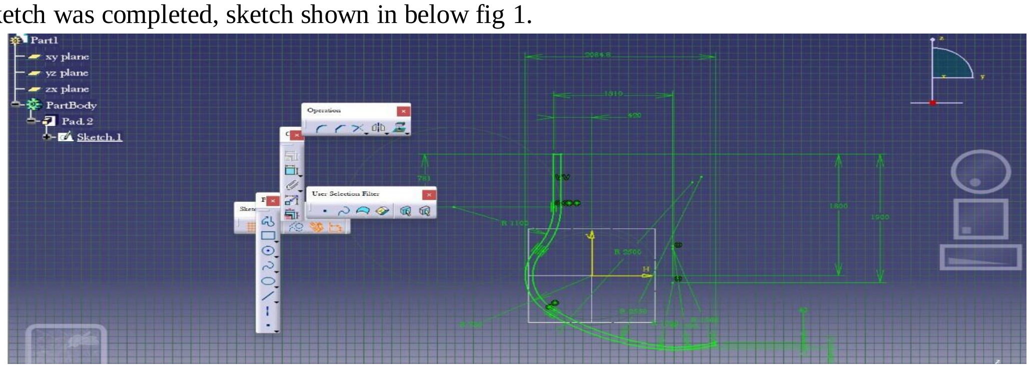

Fig 1. 2D view of prosthetic runner blade

ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 11 Issue I Jan 2023- Available at www.ijraset.com

18) On sketch based features take the pad command select the object and give the 60mm for padding/extruding.
19) The final ouput of the modeling is shown in below figures 2.
20) Select File Save As... to save the prosthetic runner blade.

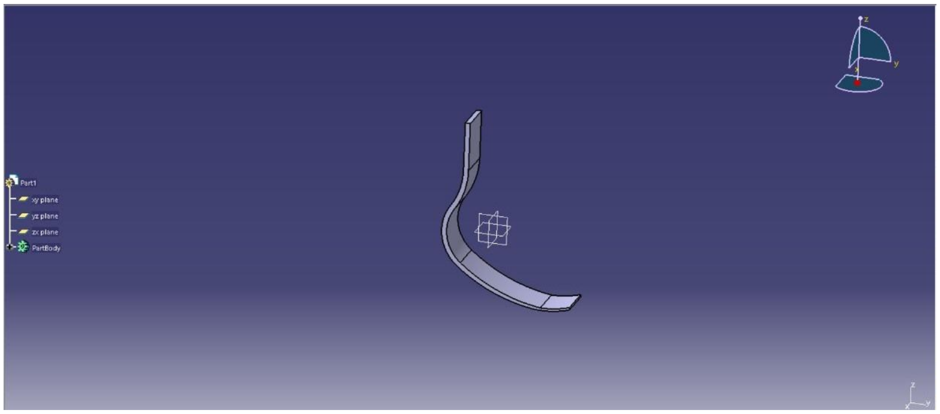

Fig 2. 3D View of prosthetic runner blade

B. Analysis

The numerical analytical method known as finite element analysis is quite effective. Stress analysis is done in that branch of solid mechanics using FEA. The fundamental tenet of the finite element method is that a body or structure may be broken down into smaller components known as finite elements. The element's characteristics are formulated and blended to produce the remedy for the whole body or structure. For a specific real-world design issue, the engineer must idealize the actual system into a FE model with accurate boundary conditions and loads acting on the system. The mathematical model is then examined for each individual element, and subsequently for the entire structure, after discretizing a particular body or structure into cells of finite elements. The many unknown parameters are calculated using the known parameters.

1) *Static Structural Analysis on Titanium Alloy:* The assumption in a static structural analysis is that the load or field conditions will be progressively applied and that they won't change over time (Not suddenly applied). The resolution of stress-related design issues is the most typical use of FEA. Because of this, every commercial programme has a wide range of stress analysis capabilities. A few tests were carried out on the blade to demonstrate how it responded to the application of the loads for which the equivalent pressure value was gathered. Maximum primary stress and strain. then demonstrate the energy storage method for the strain energy. The blade deformation proved that the load was compensated for in the design of the blade. These values were all computed using ANSYS FEA's STATIC STRUCTURAL subcategory. After drawing the model by using the CATIA V5 save the file in the igs format, after that the model imported into ANSYS workbench. Foot sub-elements were separated out using the tool Mesh so that results would be more accurate when there were many sub-elements. The number of elements and nodes in this study. Before meshing select the two materials aluminum and titanium alloy materials in the engineering materials After that give the load and the fixed support to the blade, give the fixed to the top of the side view and the force is applied to the curve and the load 590N. shown below fig 4.

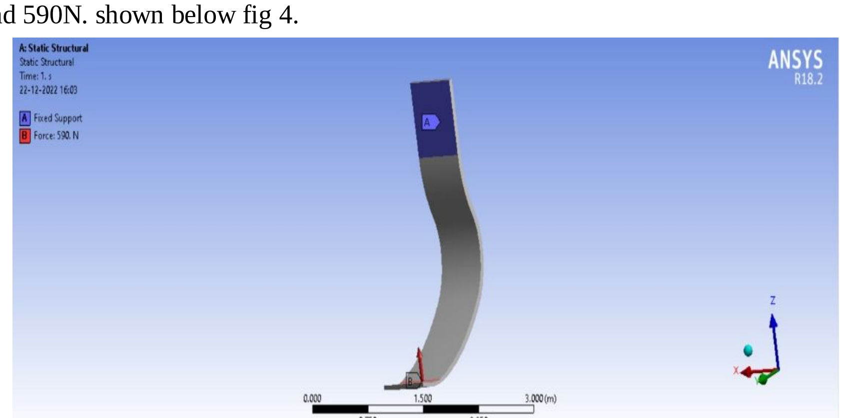

Fig 4. Assigning load conditions

After given the load conditions apply the maximum principle stress, strain, total deformation and the values shown in the below fig 5, 6, 7.

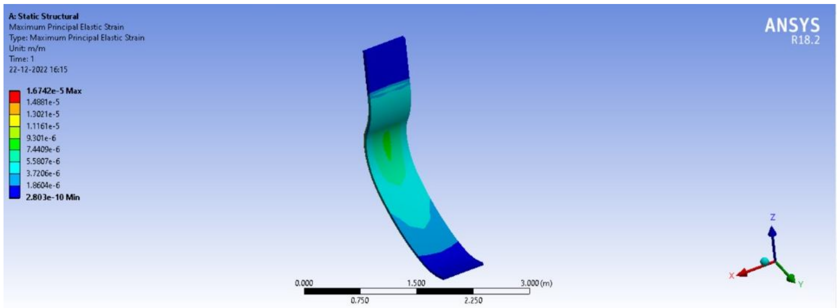

Fig 5. Maximum principal stress for titanium alloy

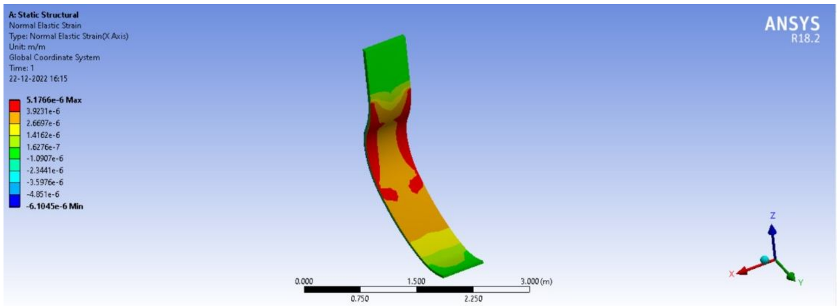

Fig 6. Strain for titanium alloy

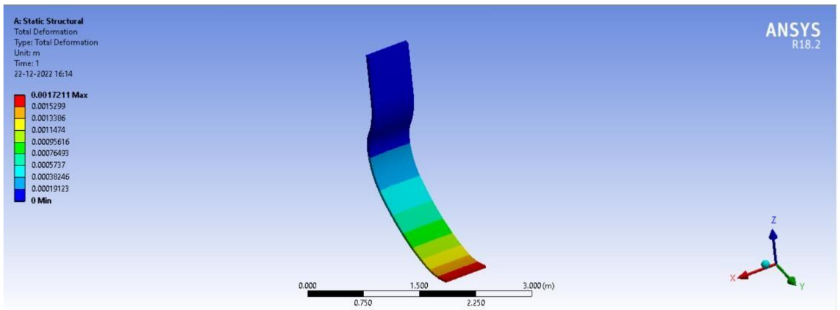

Fig 7. Total deformation for titanium alloy

2) *Static Structural Analysis on Aluminum Alloy:* Static Structural analysis are performed on the Aluminum alloy and the maximum principalstress, strain and total deformation results are shown below fig 8, 9, 10.

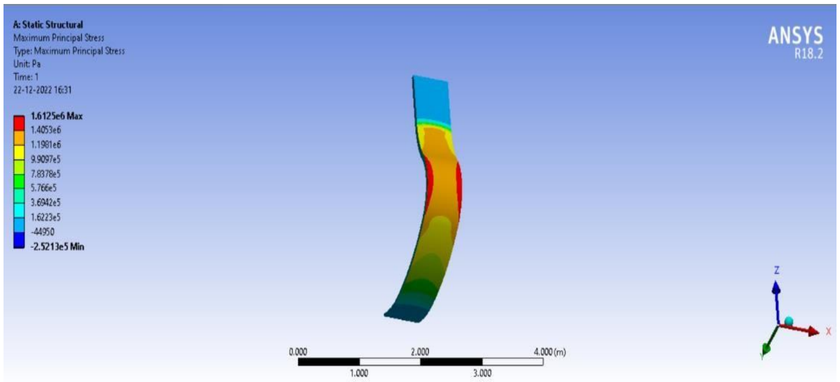

Fig 8. Stress for aluminium alloy

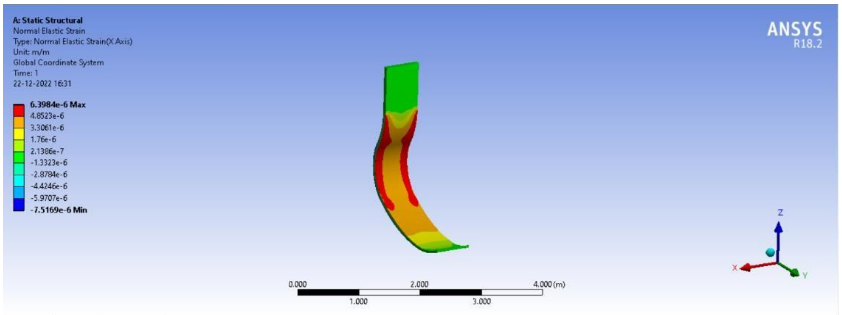

Fig 9. Strain for aluminium alloy

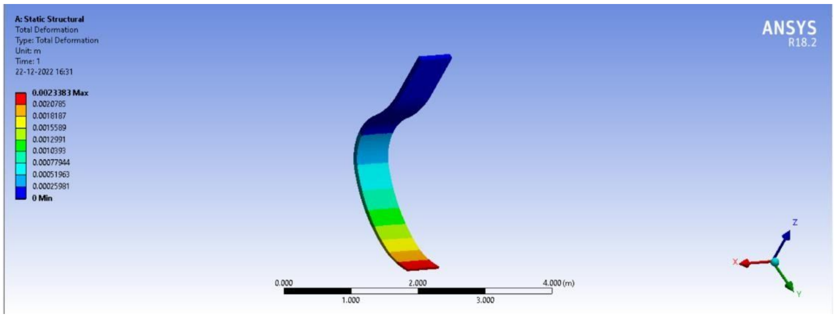

Fig 10. Deformation for aluminium alloy

V. RESULTS AND DISCUSSION

A few tests were carried out on the blade to demonstrate how it responded to the application of the loads for which the equivalent pressure value was gathered. Maximum elastic strain and Principal Stress. Then demonstrate the energy storage method for the strain energy. The blade deformation proved that the load was compensated for in the design of the blade. The STATIC STRUCTURAL subcategory of ANSYS FEA was used to calculate each of these values. The blade was loaded by the earth.

Using diverse materials, such as titanium alloy and aluminium alloy, and applying stress, strain, and deformation to both materials, a prosthetic runner blade underwent static structural analysis. When jogging, the aluminium alloy foot has a larger capacity to replenish energy than the titanium alloy foot, according to the values of strain energy. The foot made of titanium alloy deflects less than the foot made of aluminium alloy. Results are shown beneath the tables.

A. *Titanium Alloy*

The obtained stress, strain, deformation values of titanium alloy as shown in thebelow table 1

Table 1. Values of the titanium alloy

RESULTS	MINIMUM	MAXIMUM	UNITS	TIME(S)
Maximum principal stress	-2.3881e^5	1.5933e^6	pa	1s
strain	-6.1034e^-5	5.1765e^-6	m/m	1s
Total Deformation	0	0.0017211	m	1s

B. *Aluminum Alloy*

The obtained stress, strain, deformation values of aluminium alloy as shown in the below table 2

Table 2. values of the aluminium alloy

RESULTS	MINIMUM	MAXIMUM	UNITS
Maximum principal stress	-2.5213e^5	1.6125e^6	pa
strain	-7.5169e^-6	6.3984e^-6	m/m
Total Deformation	0	0.0023383	m

VI. CONCLUSION

An actual prosthetic foot was used to test a finite element model of a prosthetic foot against estimated values. The model can be used to simulate mechanical responses to forces, moments, and displacements. It also served as a useful tool for assessing the practical qualities of the prosthetic foot. The model can also be used to simulate how the device will respond as modifications are made in comparison to the original configuration.

According to the strain energy values from the ANSYS programme, the feet made of aluminium alloy are better at regenerating energy while running than the feet made of titanium alloy.

Compared to aluminium alloy feet, titanium alloy feet deflect less, which suggests that titanium alloy is stronger.

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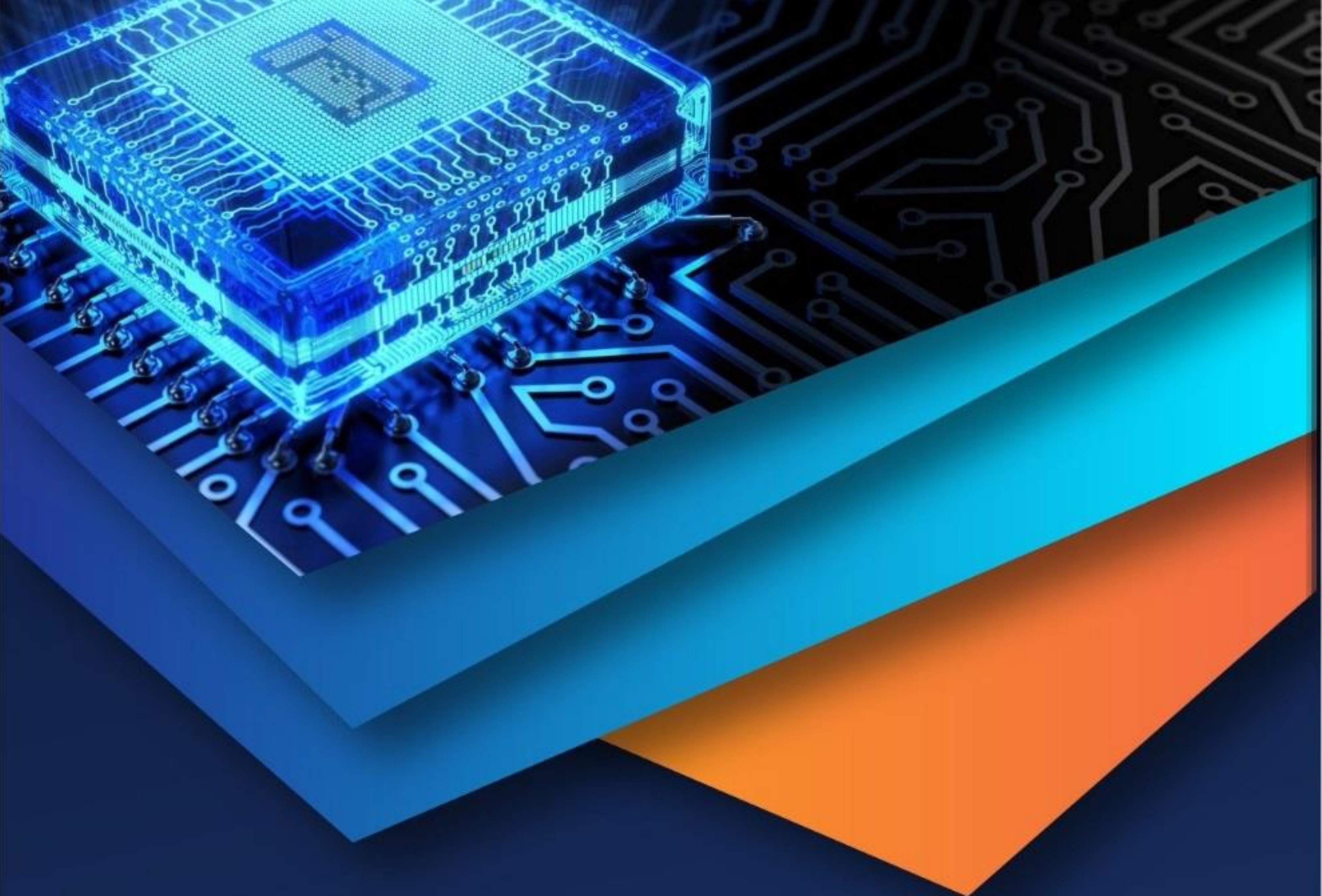

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