Static and Fatigue analysis of a Prosthetic leg under different loading conditions for medical application.

A project report submitted in partial fulfilment of the requirement for the award of the degree of

BACHELOR OF TECHNOLOGY

IN

MECHANICAL ENGINEERING

BY

K.HAKILA SATYA PRIYANAKA (318126520184)

BRUHATHI REDDY (318126520182)

S.LAKSHMIKANTH (319126520L47)

CH.SOMSEKHAR (319126520L38)

MANOJ (318126520179)

Under the esteemed guidance of

DR. K NARESH KUMAR, (Ph.D.)

ASSISTANT PROFESSORS **, Mechanical department, Anits**

PRAGNANAM BRAHMA

ANITS

DEPARTMENT OF MECHANICAL ENGINEERING ANIL NEERUKONDA INSTITUTE OF TECHNOLOGY & SCIENCES

(Permanently Affiliated to Andhra University, AICTE, Accredited by NBA NAAC with ‘A’ Grade)

SANGIVALASA, VISAKHAPATNAM (District) – 531162 2022

ANIL NEERUKONDA INSTITUTE OF TECHNOLOGY & SCIENCES

(Approved by AICTE, Affiliated to Andhra University, and Accredited by NBA and approved by NAAC) SANGIVALASA, VISAKHAPATNAM – 531162

PRAGNANAM BRAHMA

ANITS

CERTIFICATE

This is to certify that this project report entitled "**Static and Fatigue analysis of a Prosthetic leg under different loads and flexion angles for medical applications**" has been carried out by K.HAKILASATYAPRIYANKA(318126520184),CH.SOMASEKHAR(319126520L43),G.N.RBRU HATHI(318126520179),CH.MANOJ(3181265201760),S.LAKSHMIKANTH(319126520L57)under the esteemed guidance of Dr. K NARESH KUMAR, (Ph.D.), in partial fulfillment of the requirements of Degree of Bachelor of Mechanical Engineering of Andhra University, Visakhapatnam.

APPROVED BY:

28.5.22

(Prof. B. Naga Raju)
Head of the Department
Dept. of Mechanical Engineering
ANITS, Sangivalasa
Visakhapatnam.

PROFESSOR & HEAD
Department of Mechanical Engineering
ANIL NEERUKONDA INSTITUTE OF TECHNOLOGY & SCIENCES
Sangivalasa-531 162 VISAKHAPATNAM Dist A.P

PROJECT GUIDE:

Dr. K NARESH KUMAR
Assistant professor
Dept. of Mechanical Engineering
ANITS, Sangivalasa
Visakhapatnam

THIS PROJECT IS APPROVED BY THE BOARD OF EXAMINERS

INTERNAL EXAMNIER

PROFESSOR & HEAD
Department of Mechanical Engineering
ANIL NEERUKONDA INSTITUTE OF TECHNOLOGY & SCIENCES
Sangivalasa-531 162 VISAKHAPATNAM Dist A.P.

EXTERNAL EXAMINER

iii

CONTENTS

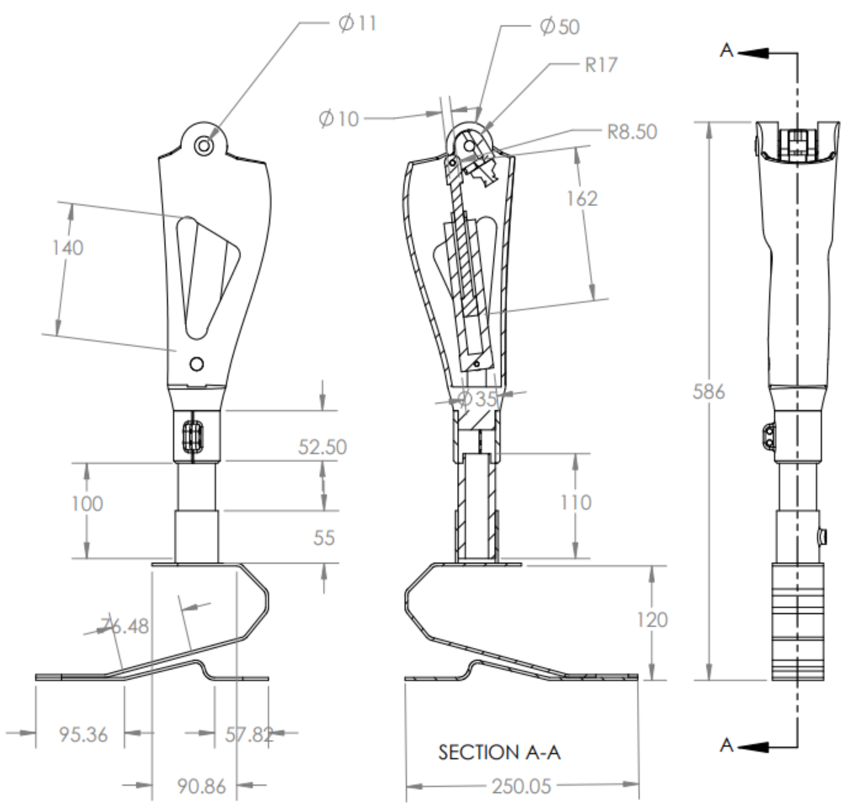
1. Introducton

1.1 What is a prosthetic leg?

Prosthetic legs are mainly used to perform leg amputations more easily and sometimes the appearance is similar to a real leg. Different types of legs have been developed in recent days to use for a specific field like running, cycling in sports. Few are designed for normal walking. The selection of materials and load bearing capacity of a leg determines its usage for any field of application. The behavior of these legs can be assessed properly by performing finite element analysis by altering the material properties and loads before designing these components.

1.2 Need of prosthetic leg

People who have lost their legs due to injury, birth have the option to use prosthetic legs for performing functional requirements of limbs. The legs developed should be resistant to wear, comfortable, reliable, moisture resistant and high load withstanding ability. When an arm or other extremity is amputated or lost, a prosthetic device, or prosthesis, can play an important role in rehabilitation. For many people, an artificial limb can improve mobility and the ability to manage daily activities, as well as provide the means to stay independent These characteristics can be achieved by proper selection of materials for manufacturing a prosthetic leg. The main part of a prosthetic leg include a socket, residual limb and base foot. The materials selected for these parts has to sustain the loads acting on it. Since 1980s there is a significant development in the usage of materials for sockets ranging from wood, leather, aluminium to plastic. At present carbon fibers are occupying better place to use as a socket material because of its excellent wear, high strength and fatigue characteristics.

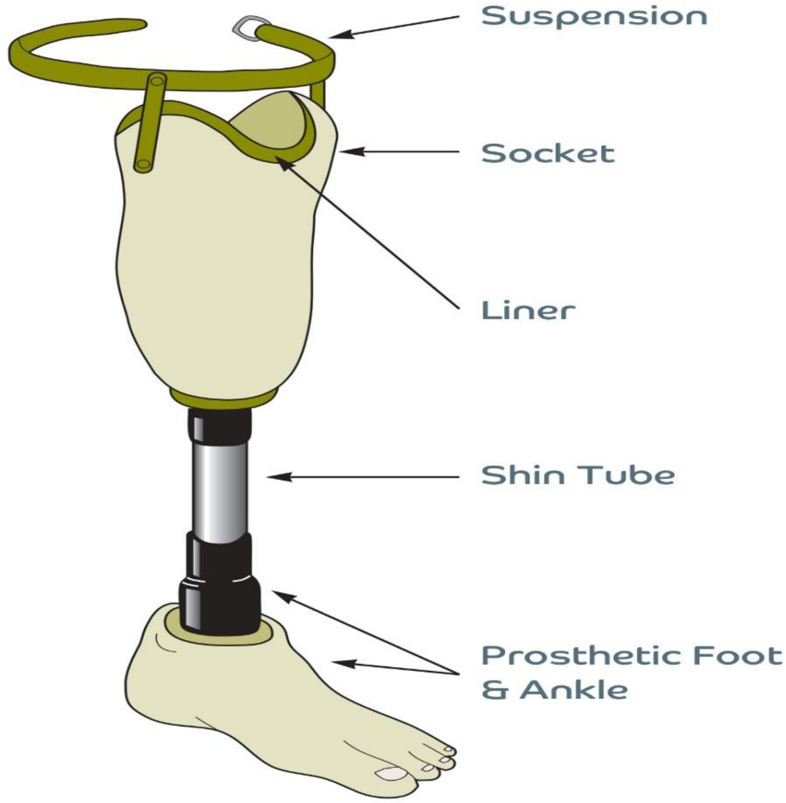


1.3 Parts of prosthetic leg

The prosthetic leg itself is made of lightweight yet durable materials. Depending on the location of the amputation, the leg may or may not feature functional knee and ankle joints.

The socket is a precise mold of your residual limb that fits snugly over the limb. It helps attach the prosthetic leg to your body. A limb prosthesis has 4 main parts.

- Interface
- Suspension
- Structural components
- Appearance components



A **gel cushion interface**, worn over the residual limb, protects the skin and helps even out pressures. Custom molded interfaces may be necessary for irregular stump contours (because of, for example, deep scars, sharp bones, or burns). Ideally, people should have 2 identical interfaces so they can be alternated day to day. Alternating the interface helps it maintain its elasticity and shape and last longer. Interfaces are typically recommended to be replaced every 6 months and, for very active patients, every 3 to 4 months.

A **prosthetic sock** may be worn instead of or with a gel interface. Socks are made of wool, nylon, or synthetic fabrics, sometimes with gel sandwiched between the layers of fabric. Socks are available in different thicknesses (plies). The residual limb changes size normally throughout the day as a result of activities, weather, and other factors. Prosthetic socks and special pads are used to manage those changes. By putting on one or more socks of different thicknesses or by taking socks off, a person can adjust the fit of the socket to make it more comfortable as the residual limb changes size during the day. When a comfortable, stable fit cannot be maintained with the use of prosthetic socks or special pads, the prosthetist (an expert who designs, fits, fabricates, and adjusts prostheses) can adjust the socket.

Suspension refers to how the prosthesis is held to the residual limb. Certain gel interface materials are better suited for specific suspension applications (such as suction, pin, or vacuum).

The following suspension systems are commonly used:

- **Vacuum:** An electric or mechanical vacuum pump removes air from the socket. This is the most effective method for holding a prosthesis to the residual limb and also helps stabilize the amount of fluid in the residual limb. Urethane gel interface materials are preferred for this type of suspension.
- **Passive suction:** When the residual limb is put in the socket, air is forced out. A seal above prevents air from reentering, creating suction. A one-way valve may be incorporated in the bottom of the socket to allow air out.
- **Interface with a locking pin:** A cushion interface that has a removable, adjustable stainless steel suspension pin at the bottom is inserted into a locking mechanism in the bottom of the plastic socket. To remove the prosthesis, the person presses a release button to disengage the pin.
- **Anatomical:** Bumps at the ends of bones, such as at the knee, ankle, or elbow, can be used to help hold the socket to the body.
- **Belts and straps:** A belt and/or straps may be used to hold the prosthesis on if the person cannot tolerate or finds the vacuum, suction, or pin systems too difficult.

For lower limbs, microprocessor-controlled ankles and knees can provide greater safety, stability, reduced energy expenditure, and diminished stress to nearby joints and the spine.

For upper limbs, body-powered prostheses require a fully functioning shoulder and arm to operate the loop strap that controls the prosthetic hand or hook. Myoelectric upper-limb prostheses do not require a fully functioning shoulder and arm and instead use the natural, electrical signals of a person's muscles. Electrodes in the socket detect muscle activity and transmit signals that operate the prosthetic hand, wrist, and/or elbow. No other body movement is required.

1.4 Classification of Prosthetic leg

1.4.1

Running-specific prostheses (RSF) are designed to replicate the spring-like nature of biological legs (bioL) during running. However, it is not clear how these devices affect whole leg stiffness characteristics or running dynamics over a range of speeds. We used a simple spring–mass model to examine running mechanics across a range of speeds, in unilateral and bilateral transtibial amputees and performance-matched controls. We found significant differences between the affected leg (AL) of unilateral amputees and both ALs of bilateral amputees compared with the bio of non-amputees for nearly every variable measured.

1.4.2 Walking Speccific Prosthesis (WSF) Prosthetic legs, or prostheses, can help people with leg amputations get around more easily. They mimic the function and, sometimes, even the appearance of a real leg. Some people still need a cane, walker or crutches to walk with a prosthetic leg, while others can walk freely. Based on the 10 MWT, the median estimated maximal covered distance in the persons with a lower limb amputation was **67 m** (with an interquartile range of 22–93).

1.5 Advantages of prosthetic legs

- Increased prosthetic use.
- A prosthesis substitutes for a part of the body that may have been missing at birth, or that is lost in an accident or through amputation.
- Longer walking distances.
- Full range of joint movement.
- Better sitting comfort.
- No skin problems.
- Stable and safer standing and sitting.
- A sense of the artificial limb belonging to the body.
- Easy and quick attachment and removal.
- Using running legs has its competitive benefits. Once an amputee runner reaches top speed, the blade prostheses allow him or her to move faster and with less effort. This is because the running blades typically weigh less than biological legs.
- High-tech prostheses allow amputees to run marathons, compete in triathlons and live productive lives.
- These new prostheses are changing the lives of people who have lost limbs in car crashes and work accidents or through other serious injuries and diseases.
- When the prosthetic legs are well fitted and the patients have good gaits, they expend less energy in walking, in comparison to walking without prosthetic legs or using crutches.
- For people with two leg amputations, the choice is between prosthetic legs and a wheelchair. Some patients, even those with single amputations, prefer the comfort of a wheelchair or choose to avoid prosthetic legs for a variety of reasons including financial ones. But, prosthetic legs allow amputees the option of going upstairs, downstairs, in tight areas or even cars and other methods of transportation with more ease. Also, there are areas that are not accessible by wheelchairs, like older buildings.
- *Finally, there is the psychological advantage.* People can gain a better psychological outlook on life by mastering the use of prosthetic legs, whether they are using one or two.

1.6 Disadvantages of prosthetic legs

- Intact Limb Pain-
  Overuse syndrome is well documented in amputees, where additional and atypical amounts of time and pressure are borne down through the intact limb. Over time, this can and will cause early degeneration of the lower back, hip, knee and ankle resulting in discomfort and other complications. This becomes even more important if there are injuries to the intact limb, which make it even more critical that theprosthesis be designed to evenly bear the load and smooth out every step in your gait.
- Back Pain.

  There are few things in life more frustrating than back pain. Walking with a poorly fit prosthesis or with sub-optimal gait habits can cause long term structural changes in the body that will result in muscular pain and eventually long term neurological pain. Most users of a prosthesis will at some time encounter back pain due to compensation for the loss of your limb. At MCOP, we work closely with the leading gait experts in prosthetics because we know that success with a prosthesis is the result of the sum of many parts. The socket, the technology, the training, and the breaking of bad gait habits are all essential to address the issues that cause back pain.
- Current Prosthetic Not Meeting Your Needs.

  The first rule of prosthetics is safety first. Once safety is ensured, efficiency and dynamics become the next key to choosing the right prosthetic technology. If you feel held back by your current prosthetic, or are unable to do certain activities, you may not have the right prosthetic technology for your needs. A number of specialized prosthetic designs exist for every need, whether you wear a prosthetic to ride a bike, ski or snowboard, sprint, or run long distances, the technology is out there. There are shock absorbing prosthetic designs for high impact activities, and designs that are lightweight and optimized for easy low impact walking.
- Poor Balance, Instability, or a Fear of Falling.
  If however your socket fits well and you are comfortable then there is likelihood that the “alignment” of your prosthetic components are not optimized. If you are experiencing what feels like rotation of a knee or foot, a sensation of walking on the edge of your foot, or feel like you have a hitch in your step then adjustments are likely needed to your prosthesis to remedy the issue.

- General Fatigue and Reduced Mobility.
  Struggling with fatigue when walking or when entering and exiting a seated position, some of this may be due to your prosthesis. Whether your goal is to simply stand up with confidence, walk around the house, or run a 10K, your prosthetic plays a large role in your ability, and should not hold you back.
- Irritation and Skin Issues.
  Research has shown that as many as 74% of amputees have skin issues.
- Socket Issues or Discomfort.
  Proper socket fitting requires a skilled clinician and a plan tailored to your unique needs. Without a sound clinical plan, socket fitting can take far too long, yet still provide little in the way of improvement and comfort. Unfortunately, a one-size-fits-all approach is used in the prosthetic industry, which inevitably compromises comfort and your ability

1.7 Using a Prosthetic Device

When an arm or other extremity is amputated or lost, a prosthetic device, or prosthesis, can play an important role in rehabilitation. For many people, an artificial limb can improve mobility and the ability to manage daily activities, as well as provide the means to stay independent.

1.7.1 Choosing and Using a Prosthesis

A number of factors are involved in choosing a prosthesis. They include:

- The location and level of the amputation
- The condition of the remaining limb
- Your activity level, particularly for a prosthetic leg or foot
- Your specific goals and needs

Prostheses are designed and fitted by a specialist called a prosthetist. The fitting process may begin in the hospital shortly after amputation after the swelling has gone and down and the incision is healed. It involves:

- Measuring the stump and the healthy opposite limb
- Fitting silicone liner
- Making a plaster mold
- Fashioning the socket
- Forming the plastic parts and then creating the metal parts of the limb
- Attaching the shaft
- Aligning the prosthesis

Depending on your comfort and how well your wound is healing, you may begin to practice with your artificial limb as early as a few weeks after surgery. A physical or occupational therapist will train you on how to use and care for it.

1.7.2 Prosthetic Comfort and Care

To gain the greatest benefits of the new limb and help prevent problems, it is important to take care of the device, the amputation site, and your general health by doing the following every day:

- Remove the prosthesis before going to bed. Examine the device for loose parts or damage. Examine the stump for blisters or other signs of irritation.
- Clean and put a small amount of lotion on the stump and massage the skin.
- Place a bandage on the stump to decrease swelling when you are not wearing the prosthesis.
- Regularly inspect the skin of the stump to look for sores or wounds. You may need to have someone else help you look or use a mirror.
- Practice exercises recommended by your physical therapist. These will include exercises for stretching, range of motion, body positioning, and endurance.
- For leg prostheses, wear proper fitting shoes and never change the height of your heels. The prosthesis is designed for one heel height only.
- Clean the prosthesis' socket with soap and water.
- Wear clean dry socks with the prosthesis.

It is also important to maintain a stable body weight. This will help to keep the prosthesis fitting properly. You should also have the prosthesis examined and serviced once a year to make sure it is in proper working order.

2. Geometrical Modeling

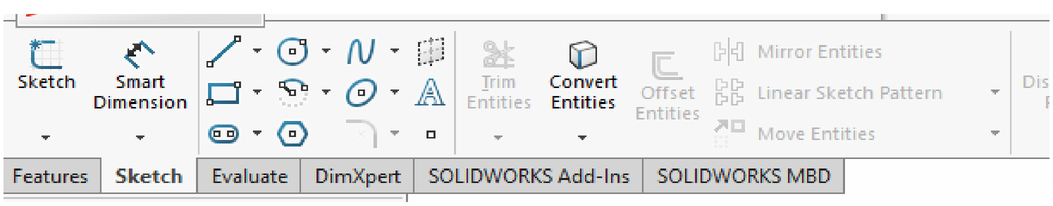
2.1 Solid Works

The SOLID WORKS CAD software is a mechanical design automation application that lets designers quickly sketch out ideas, experiment with features and dimensions, and produce models and detailed drawings.

Building a model in Solid Works usually starts with a 2D sketch (although 3D sketches are available for power users. The sketch consists of geometry such as points, lines, arcs, conics (except the hyperbola), and splines. Dimensions are added to the sketch to define the size and location of the geometry. Relations are used to define attributes such as tangency, parallelism, perpendicularity, and concentricity. The parametric nature of SolidWorks means that the dimensions and relations drive the geometry, not the other way around. The dimensions in the sketch can be controlled independently, or by relationships to other parameters inside or outside the sketch.

- Solid Works Command Manager

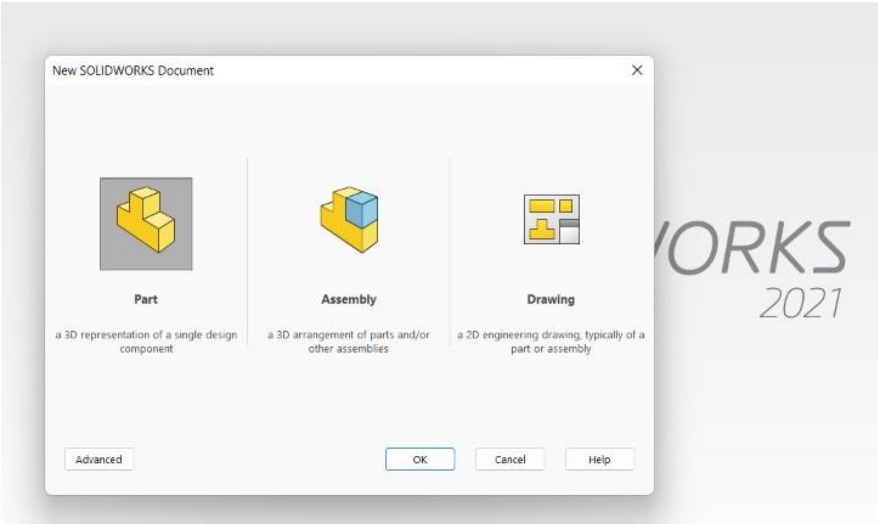
Command Manager:



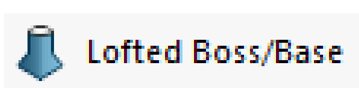
Solid Works Features toolbar:

2.2 Stages in the Process:

Create a New part:



- **Create a New part document**:
  New parts can be created in inch, millimeter or other units. Parts are used to create and hold the solid model.
- **Sketch the profile**:
  Sketches are collections of 2D geometry that are used to create solid features. These include lines, circles and rectangles.
- **Applying Sketch relations and dimensions:**
  Geometric relationships such as horizontal and vertical are applied to the sketch geometry. Dimension size the geometry while the relations restrict the movement of the entities.
- **Extruding the sketch:**
  Extruding uses the 2D sketch to create a 3D solid feature

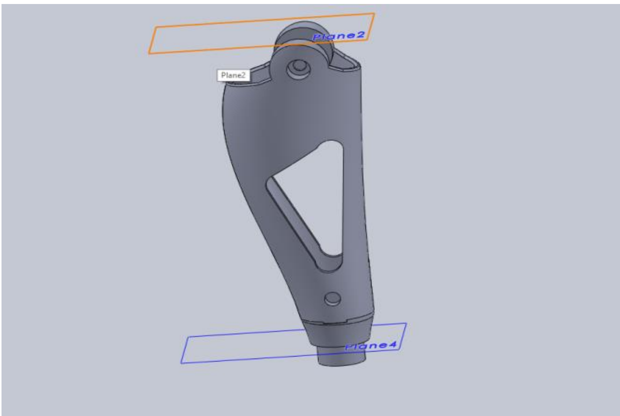


2.3 Parts designed using solidworks:

2.3.1 Limb

This is the main part of the prosthesis. There are two common types that are used for legs.

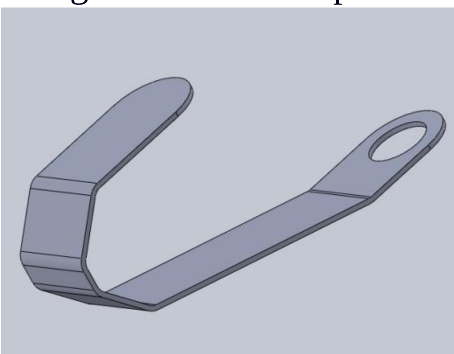
- Below the knee: When a lower prosthetic leg is attached to an intact upper leg.
- Above the knee: A lower and upper prosthetic leg with a knee.
- The design of it will be dependent on each individual and their preferences.

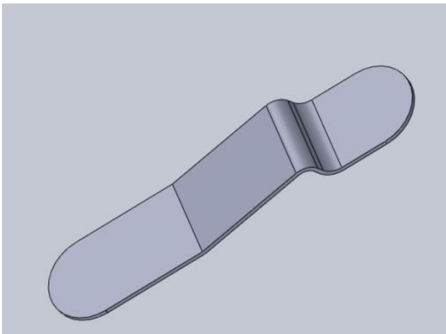


(This part is Below the knee limb part : When a lower prosthetic leg is attached to an intact upper leg.)

2.3.2 Feet with Energy Return / Dynamic Response Feet

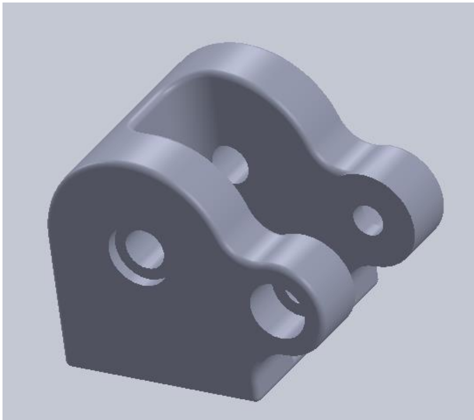
The basic element of these feet is the design of the keel that simulates a spring molded carbon fiber plates. This design has better energy response during the toe-off phase (imitating the natural impulse of the foot) by means of the shape and the material of the keel. The foot store and release energy when the individual is walking by absorbing the energy from the keel in the "roll-over" phase of walking. This creates a push off action.





2.3.3 Rotator

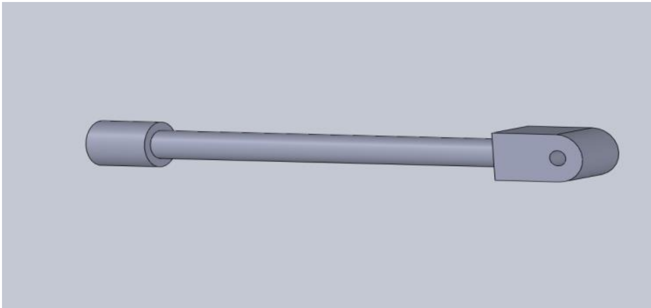
A device for joining a prosthetic foot to a prosthetic ankle block with limited, resilient rotation there between includes a generally cylindrical adapter or housing secured in the lower end of the ankle block, coaxial with the vertical pivot axis of the foot. An outer spool is secured within the adapter, and an inner spool freely rotates therein on two bearings disposed between the spools and spaced axially there along. A rubber annulus is disposed between the spools intermediate to the bearings, and vulcanized in place to adhere to both spools and form a resilient link there between. A pin extends downward from the outer spool to engage a slot in the foot and limit the rotation thereof.



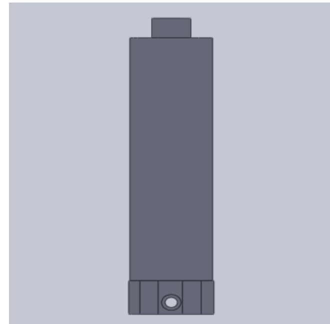
Rotator

2.3.4 Pistoning

One of the most obvious losses of suspension is “pistoning”. Pistoning happens when your residual limb lifts out of your socket when you take weight off of it and pushes in when you apply weight. Each step your limb moves up and down in the socket like a piston. This means that every time you lift your leg, there is a delay before your prosthesis begins to move. It also means you must pick your whole leg up that much higher to clear the ground.



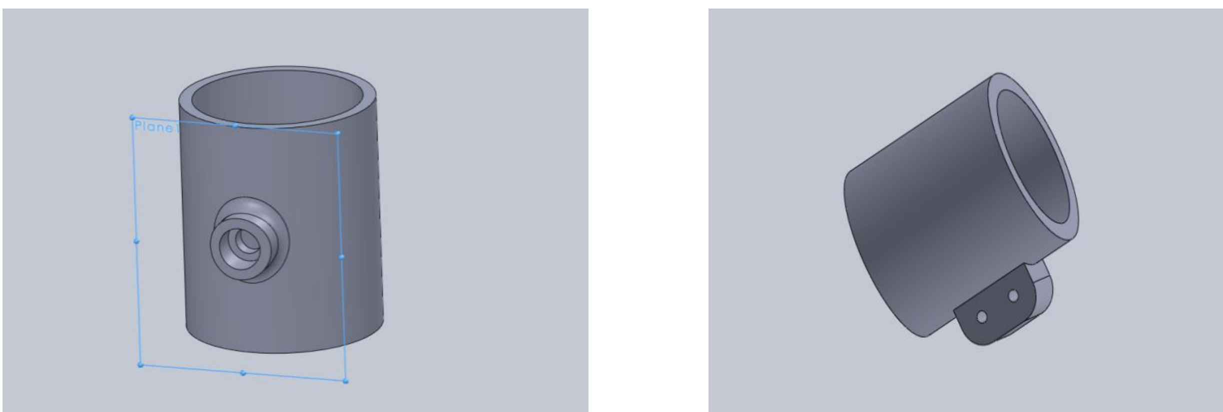
Piston



Piston shaft

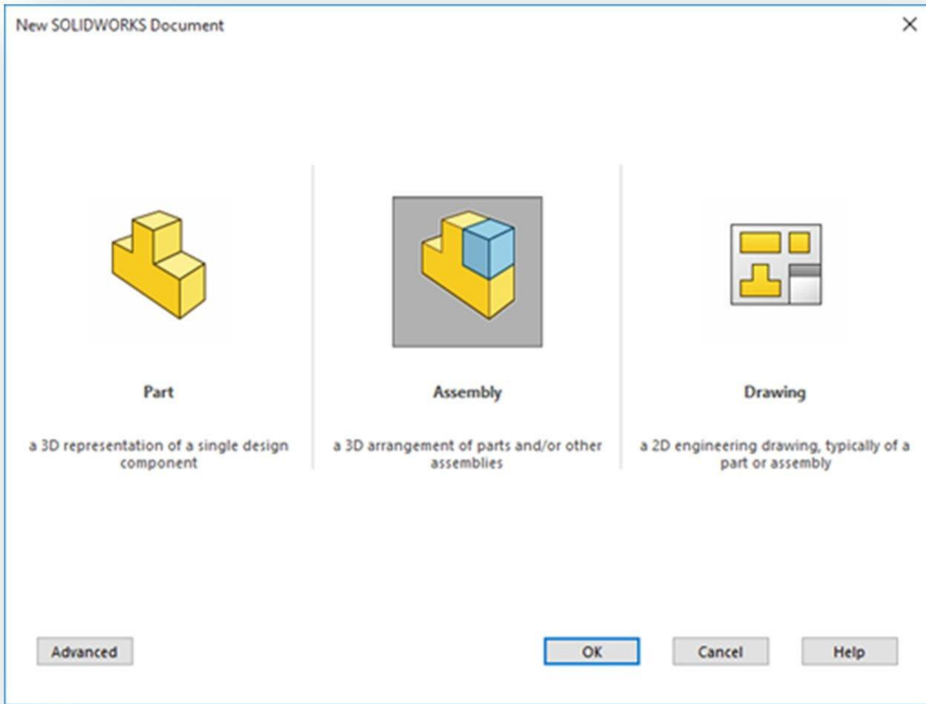
2.3.5 Pylon

Lower limbs tubes or pylons are prosthetics components that are claimed to support loads during walking and other daily tasks activities, i.e., in lower limb amputations, when attached to a socket it replaces the role of the tibia and fibula bones as support structure.



Pylons

2.4 Assembly



To create an assembly from a part:

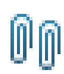
- Click Make Assembly from Part/Assembly  (Standard toolbar) or File > Make Assembly from Part.

- Click in the graphics area to add the part to the assembly.

  SOLIDWORKS makes the first component fixed.

Mating in solid works assembly

Mates create geometric relationships between assembly components. As you add mates, you define the allowable directions of linear or rotational motion of the components. You can move a component within its degrees of freedom, visualizing the assembly's behavior.

In the Mates folder, these icons indicate the mate type. 

Standard Mates by Entity

Mates create geometric relationships, such as coincident, perpendicular, tangent, and so on. Each mate is valid for specific combinations of geometry. The following tables list the valid mates for all geometry types.

Types of Mates:

Spherical and Curvilinear Mates

you can create mates using spherical bodies and surfaces.

Smart Mates

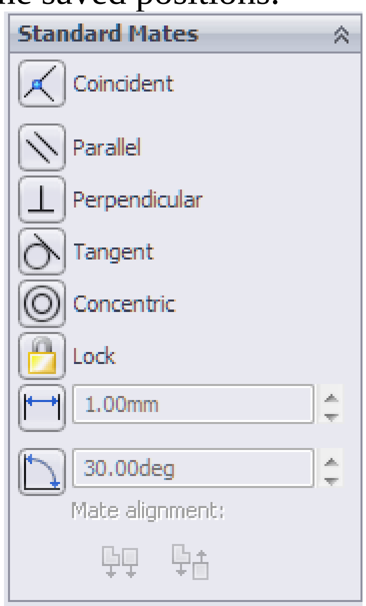
The SmartMates functionality saves time by allowing you to create commonly-used mates without using the Mate Property Manager.

Visualizing Mate Systems

You can visualize, manipulate, and troubleshoot mates using the View Mates window, View Mate Errors window, and mate callouts.

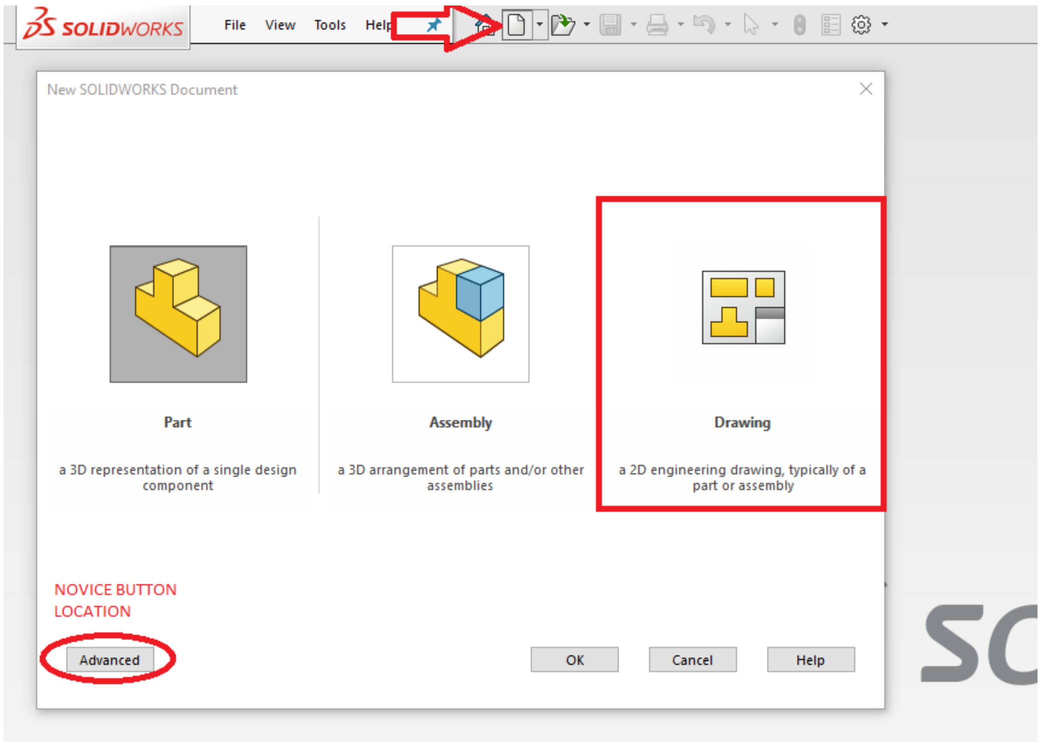
Mate Controller

Mate Controller lets you manipulate specific mates that control degrees of freedom for a design. You can save and recall saved positions and mate values. You can create animations based on the saved positions.



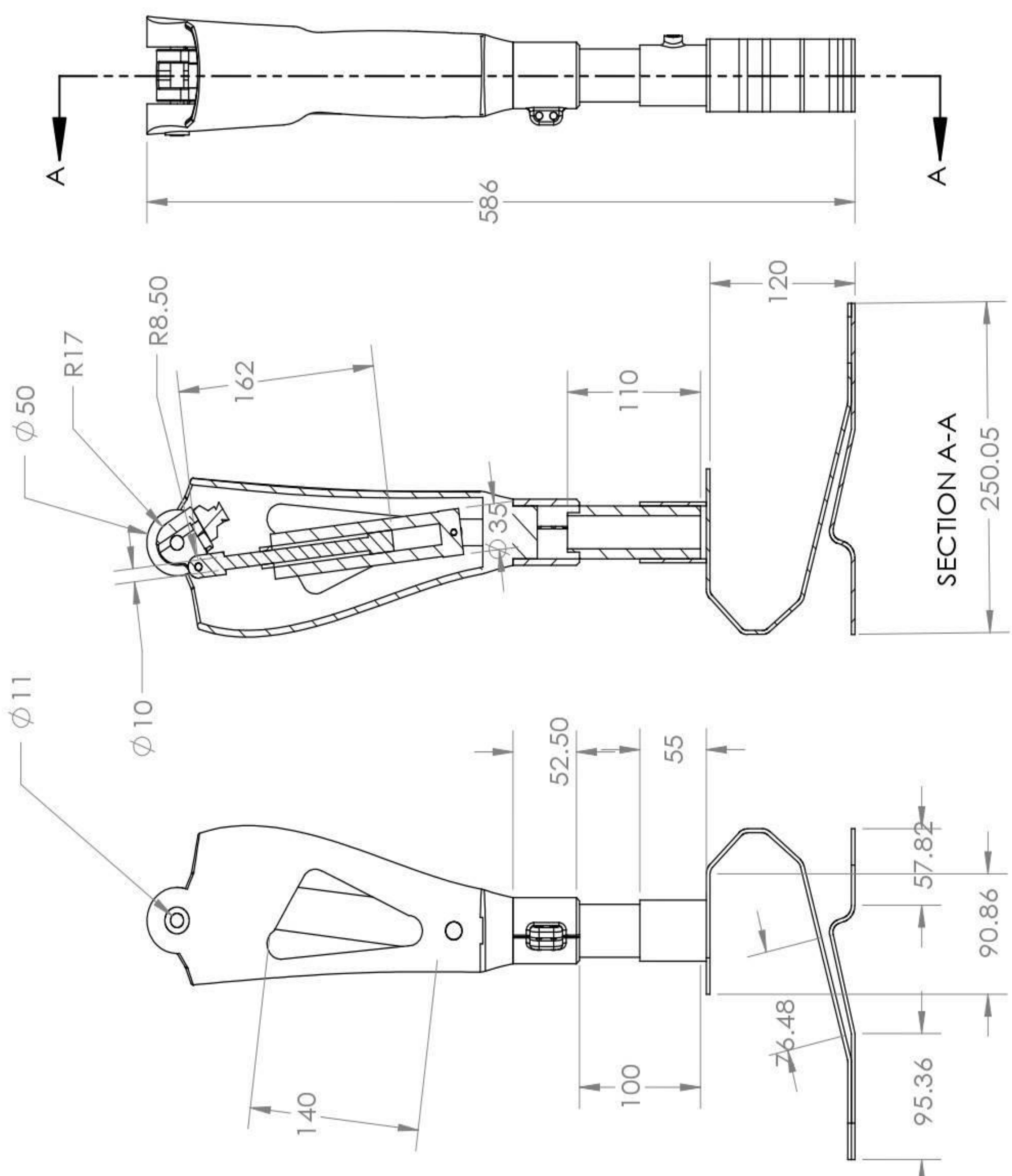
(Assembled prosthetic leg using solidworks software)

2.5 Creating Drawings



You can generate drawings in SolidWorks the same way you would generate them in 2D drafting and drawing systems. However, creating 3D models and generating drawings from the model have many advantages; for example:

- Designing models is faster than drawing lines.
- SolidWorks creates drawings from models, so the process is efficient.
- You can review models in 3D and check for correct geometry and design issues before generating drawings, so the drawings are more likely to be free of design errors.
- You can insert dimensions and annotations from model sketches and features into drawings automatically, so you do not have to create them manually in drawings.
- Parameters and relations of models are retained in drawings, so drawings reflect the design intent of the model.
- Changes in models or in drawings are reflected in their related documents, so making changes is easier and drawings are more accurate.



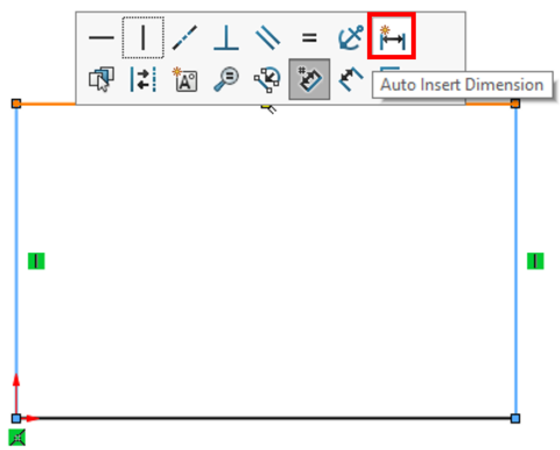
(All dimension units are millimeters (mm)).

2.5.1 To add a dimension to a sketch or drawing:

SOLIDWORKS 2016 introduced a new way of adding dimensions in a sketch. From this version you can preselect sketch entities and then use the **Smart Dimension** tool to add dimensions to the entities. But quite some people found this setting annoying, because in some cases the dimension was placed at a previously selected and unwanted location. So this setting has been undone in SOLIDWORKS 2018, which brings back the SOLIDWORKS 2015 behavior for Smart Dimension.

To compensate this, another setting was added. Starting from SOLIDWORKS 2018 you can dimension entities with the **Auto Insert Dimension** tool on the context toolbar.

In the image below, the two vertical lines are pre-selected with the Ctrl-key. Then, on the context toolbar, **Auto Insert Dimension**  is selected.



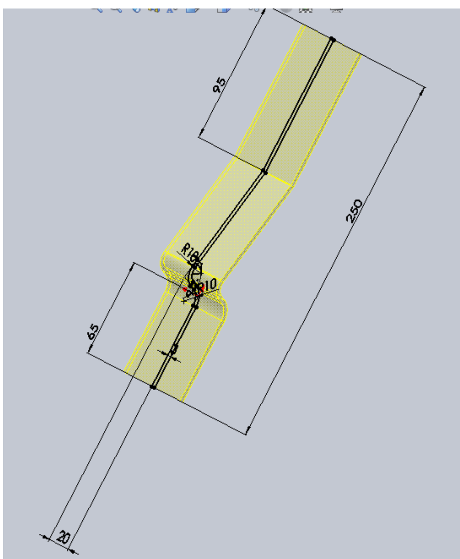
The Modify dialog box appears, so you can type a dimension. And after pressing **Enter**, the dimension is applied to the selected entities.

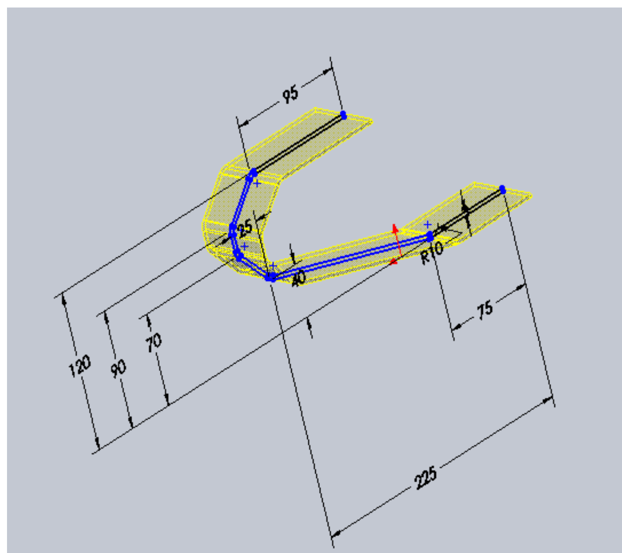
The entities supported by this tool on the context toolbar are:

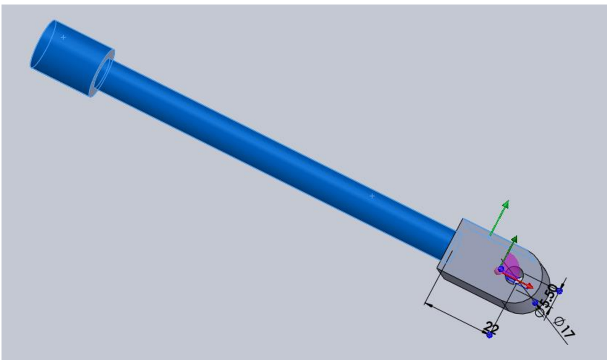
- Line: Linear dimension

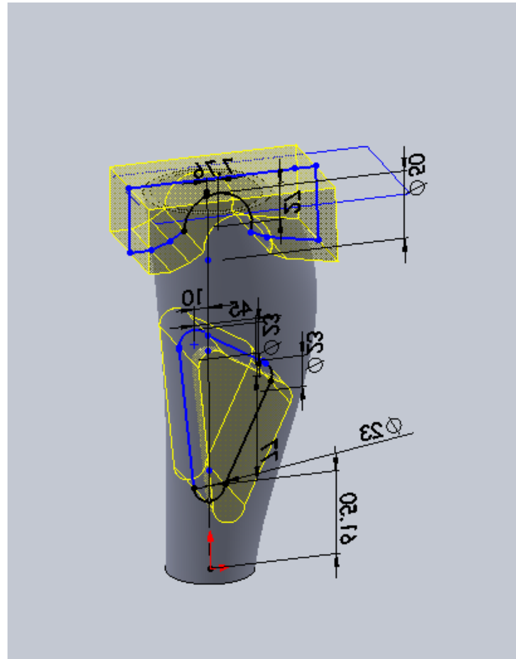
- Arc: Radial dimension
- Circle: Diameter dimension
- Two lines at an angle: Angular dimension between entities
- Two parallel lines: Linear dimension between entities
- Arc or circle, and line: Linear dimension between line and center point
- Point and line: Linear dimension between line and point
- Arc or circle, and point: Linear dimension between point and center point
- Arc/Arc or Circle/Circle or a combination thereof: Linear dimension between center points

2.5.2 Dimensions of designed parts using solidworks

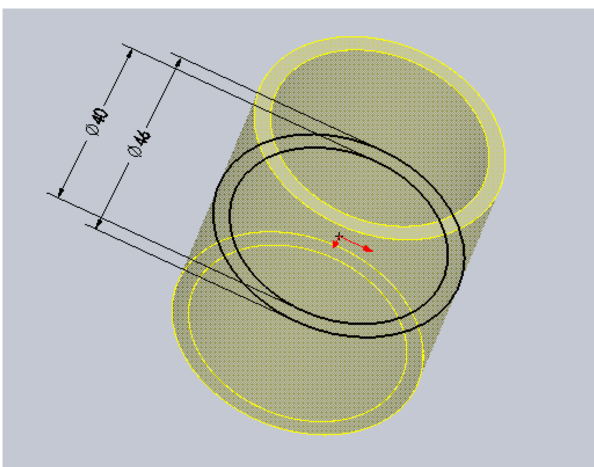


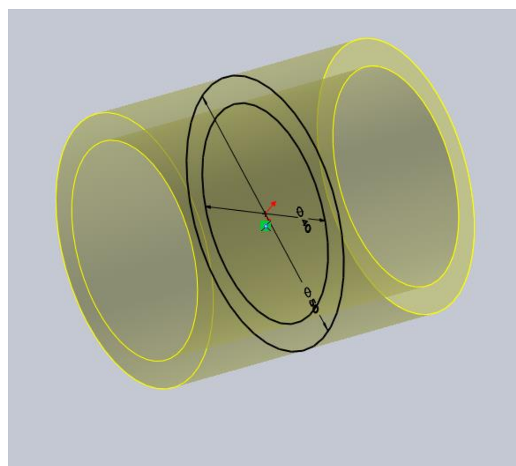


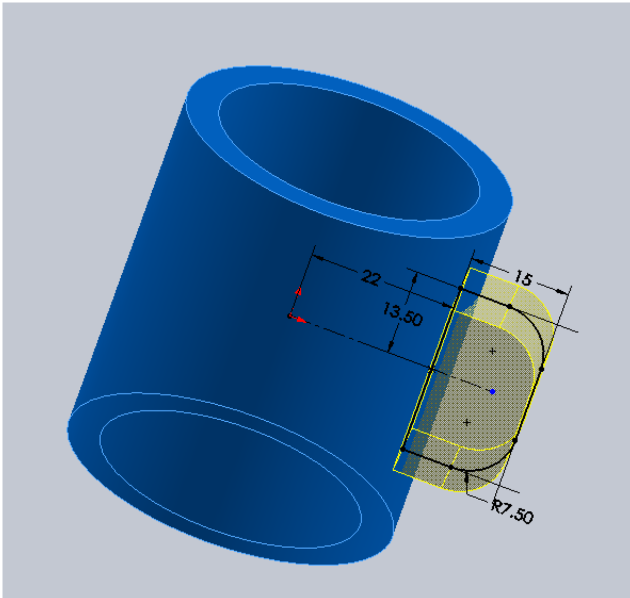


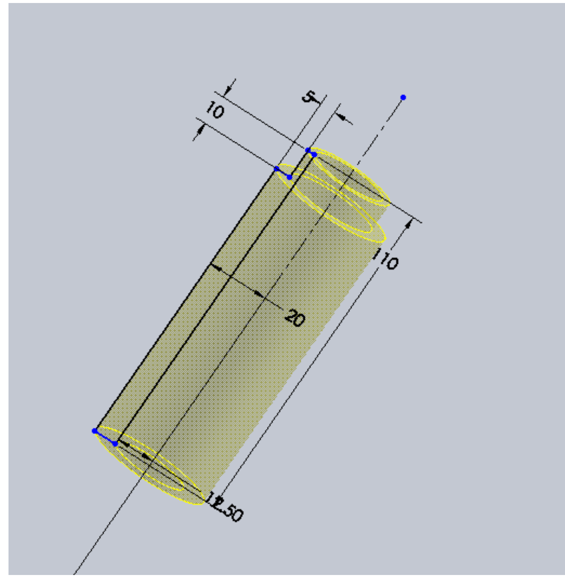


(All dimension units are millimeters (mm)).

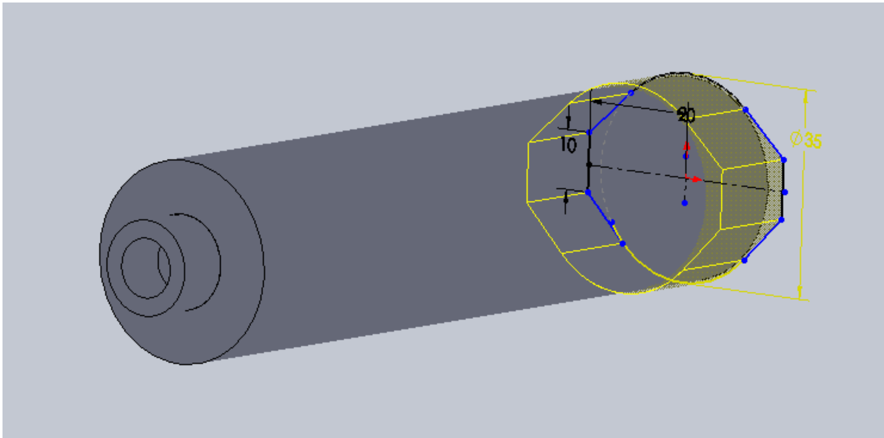








(**All dimension units are millimeters (mm)**).

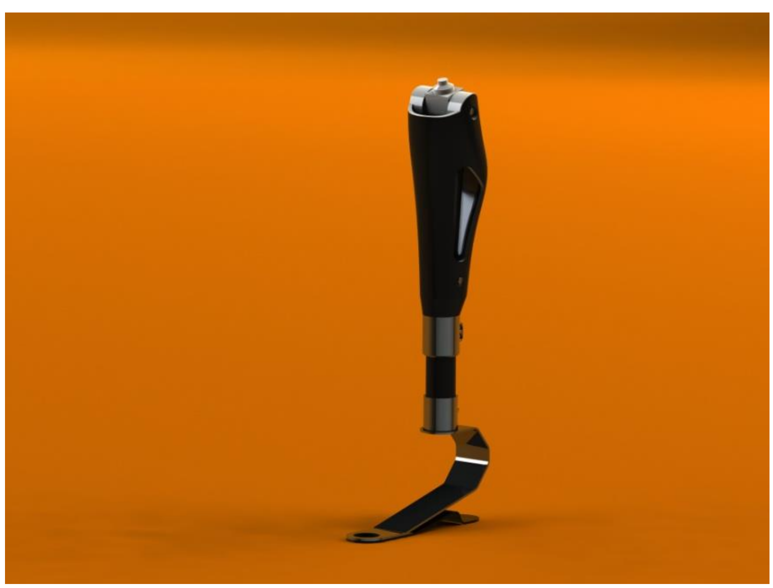


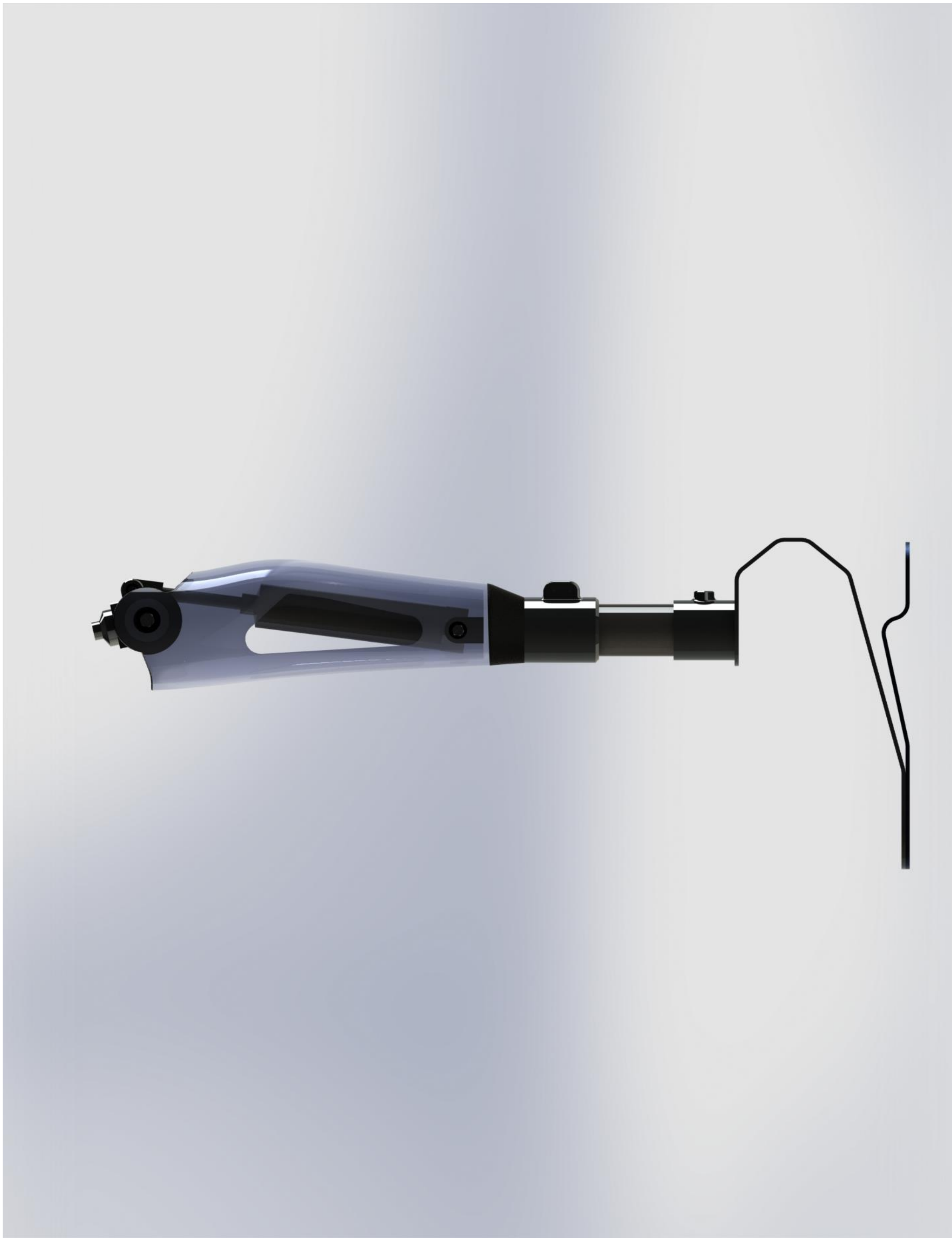
(**All dimension units are millimeters (mm)**).

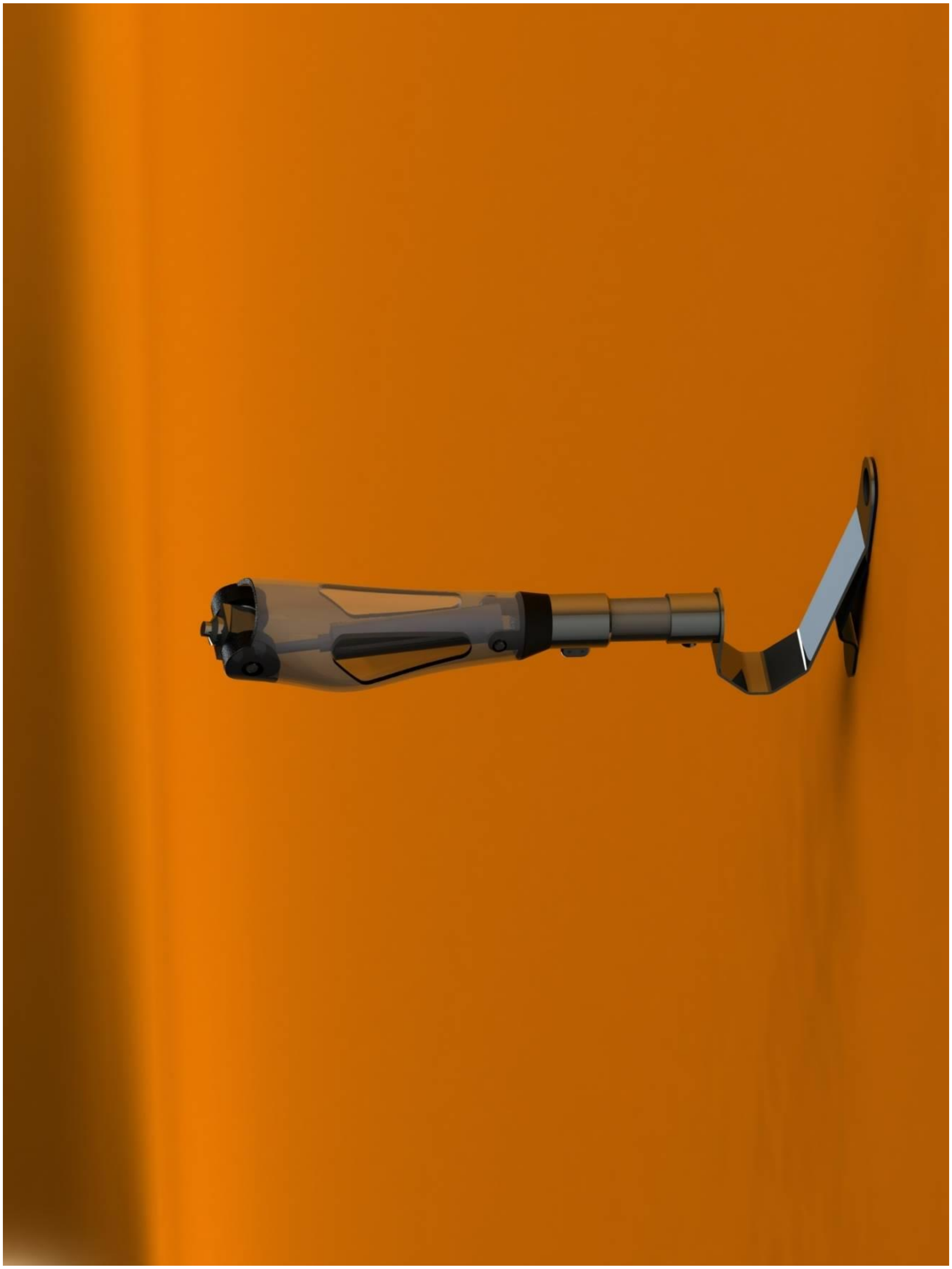
The above prosthetic leg was designed with the reference of the below link:-

https://grabcad.com/library/prosthetic-leg-7

2.6 Finished designed prosthetic leg using solidworks software







carbon fibre apoxy $(10^0, 80kgs)$

Step1 – Element connectivity table

ELEMENT	NODES
1	1-2
2	2-3

Step2 - node-coordinate table

POINT	x	Y
1	0	0
2	246.25	43.42
3	246.25	195.920

Direction cosine table:

ELEMENT	le	L=(X2-X1)/Le	m= (y2-y1)/le
1	250.05	0.984	0.173
2	152.5	0	0.999

Step3: Element stiffness matrix

$$K^1 = \frac{A_1 E_1}{L_e}\begin{pmatrix} l^2 & l_m & -l^2 & -l_m \\ l_m & m^2 & -l_m & -m^2 \\ -l^2 & -l_m & l^2 & l_m \\ -l_m & -m^2 & l_m & m^2 \end{pmatrix}$$

$A_1 = 115mm^2 \; A_2 = 706.86mm \; E = 130GPa = 13\times10^3 N/mm^2$

$$K^1 = \begin{pmatrix} 0.968 & 0.17 & -0.968 & -0.17 \\ 0.17 & 0.029 & -0.17 & -0.029 \\ -0.968 & -0.17 & 0.968 & 0.17 \\ -0.17 & -0.029 & 0.17 & 0.029 \end{pmatrix} \times \frac{150\times130\times10^3}{250.05}$$

$$K^1 = 10^3 \begin{pmatrix} 57.87 & 9.83 & -57.87 & -9.838 \\ 9.83 & 0.28 & -9.83 & -0.28 \\ -57.87 & -9.83 & 57.87 & 9.838 \\ -9.83 & -0.28 & 9.83 & 0.28 \end{pmatrix}$$

$$K^2 = \frac{A_2 E_2}{L_e}\begin{pmatrix} l^2 & l_m & -l^2 & -l_m \\ l_m & m^2 & -l_m & -m^2 \\ -l^2 & -l_m & l^2 & l_m \\ -l_m & -m^2 & l_m & m^2 \end{pmatrix}$$

$$K^2 = \frac{706.86\times130\times10^3}{152.5}\begin{pmatrix} 0 & 0 & 0 & 0 \\ 0 & 0.998 & 0 & -0.998 \\ 0 & 0 & 0 & 0 \\ 0 & -0.998 & 0 & 0.998 \end{pmatrix}$$

$$K^2 = 10^3 \begin{pmatrix} 0 & 0 & 0 & 0 \\ 0 & 601.36 & 0 & -601.36 \\ 0 & 0 & 0 & 0 \\ 0 & -601.36 & 0 & 601.36 \end{pmatrix}$$

step4 : global stiffness matrix

$$K \rightarrow K^1 + K^2 = 10^3 \begin{pmatrix} 57.87 & 9.83 & -57.87 & -9.838 \\ 9.83 & 0.28 & -9.83 & -0.28 \\ -57.87 & -9.83 & 57.87 & 9.838 \\ -9.83 & -0.28 & 9.83 & 0.28 \end{pmatrix} + 10^3 \begin{pmatrix} 0 & 0 & 0 & 0 \\ 0 & 601.36 & 0 & -601.36 \\ 0 & 0 & 0 & 0 \\ 0 & -601.36 & 0 & 601.36 \end{pmatrix}$$

$$K = 10^3 \begin{pmatrix} 57.87 & 9.83 & -57.87 & -9.83 & 0 & 0 \\ 9.83 & 0.285 & -9.83 & -0.285 & 0 & 0 \\ -57.87 & -9.83 & 57.87 & 9.83 & 0 & 0 \\ -9.83 & -0.285 & 9.83 & 0.285 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & -0.99 & 0 & 0.99 \end{pmatrix}$$

step5 : global load factor

$[F] = [K][q]$ since f1,f2,f3,f4,f5,q1,q2,q5 = 0.

$$\begin{pmatrix} 0 \\ 0 \\ -784.8 \end{pmatrix} = \begin{pmatrix} 57.87 & 9.83 & 0 \\ 9.83 & 1.28 & -0.998 \\ 0 & -0.998 & 0.998 \end{pmatrix}$$

equations

$10^3(57.87q_3 + 9.83q_4) = 0 \rightarrow eq1$

$10^3(9.83q_3 + 1.28q_4 - 0.998q_6) = 0 \rightarrow eq2$

$10^3(-0.998q_4 + 0.998q_6) = 0 \rightarrow eq3$

by solving the eq1,eq2,eq3

$q_3 =$ -0.0961=0.096mm , $q_6 =$ -0.220=0.220mm, $q_4 =$ 0.5652mm

step6 : results

$$\sigma_1 = \frac{E}{l_e}[-1\ -m\ 1\ m]\begin{bmatrix} q_1 \\ q_2 \\ q_3 \\ q_4 \end{bmatrix}$$

$$= \frac{130\times10^3}{250.05}\left[-0.98\ -0.17\ 0.98\ 0.17\right]\begin{bmatrix} 0 \\ 0 \\ 0.096 \\ 0.220 \end{bmatrix}$$

$$\sigma_1 = 68.834 N/mm^2 = 6.8\times10^7 Pa$$

$$\sigma_2 = \frac{E}{l_e}[-1\ -m\ 1\ m]\begin{bmatrix} q_3 \\ q_4 \\ q_5 \\ q_6 \end{bmatrix} = \frac{130\times10^3}{152.5}[0\quad -0.999\quad 0\quad 0.999]\begin{bmatrix} 0.096 \\ 0.220 \\ 0 \\ 0.220 \end{bmatrix}$$

$$\sigma_2 = 0$$

Titanium at 80kg & 20°

Step1 - Element connectivity table:-

ELEMENT	NODES
1	1-2
2	2-3

Step 2 -
Node-coordinate table :-

POINT	x	Y
1	0	0
2	234.97	85.522
3	234.97	237.72

Direction cosine table:-

ELEMENT	le	L=(X2-X1)/Le	m= (y2-y1)/le
1	250.05	0.93	0.34
2	152.5	0	0.998

Step3: Element stiffness matrix:-

$$K^1 = \frac{A_1 E_1}{L_e}\begin{pmatrix} l^2 & lm & -l^2 & -lm \\ lm & m^2 & -lm & -m^2 \\ -l^2 & -lm & l^2 & lm \\ -lm & -m^2 & lm & m^2 \end{pmatrix}$$

$$A_1 = 115mm^2 \quad E = 120GPa = 12\times10^3 N/mm^2$$

Here l = 0.93 m = 0.34

$$K^1 = \begin{pmatrix} 0.86 & 0.316 & -0.86 & -0.316 \\ 0.316 & 0.1156 & -0.316 & -0.1156 \\ -0.86 & -0.316 & 0.86 & 0.316 \\ -0.316 & -0.1156 & 0.316 & 0.1156 \end{pmatrix} \times \frac{115\times120\times10^3}{250.05}$$

$$K^1 = 10^3\begin{pmatrix} 47.45 & 17.43 & -47.45 & -17.43 \\ 17.43 & 6.37 & -17.43 & -6.37 \\ -47.45 & -17.43 & 47.45 & 17.43 \\ -17.43 & -6.37 & 17.43 & 6.37 \end{pmatrix}$$

Here l = 0 m = 0.998

$$K^2 = \frac{A_2 E_2}{L_e}\begin{pmatrix} l^2 & lm & -l^2 & -lm \\ lm & m^2 & -lm & -m^2 \\ -l^2 & -lm & l^2 & lm \\ -lm & -m^2 & lm & m^2 \end{pmatrix}$$

$$A_2 = 706.86 mm \quad E = 120 GPa = 12\times10^3 N/mm^2$$

$$K^2 = \frac{706.86\times120\times10^3}{152.5}\begin{pmatrix} 0 & 0 & 0 & 0 \\ 0 & 0.998 & 0 & -0.998 \\ 0 & 0 & 0 & 0 \\ 0 & -0.998 & 0 & 0.998 \end{pmatrix}$$

$$K^2 = 10^3\begin{pmatrix} 0 & 0 & 0 & 0 \\ 0 & 553.98 & 0 & -553.98 \\ 0 & 0 & 0 & 0 \\ 0 & -553.98 & 0 & 553.98 \end{pmatrix}$$

$$step4: global\ stiffness\ matrix:-$$

$$K \to K^1 + K^2$$

$$=10^3\begin{pmatrix} 47.45 & 17.43 & -47.45 & -17.43 \\ 17.43 & 6.37 & -17.43 & -6.37 \\ -47.45 & -17.43 & 47.45 & 17.43 \\ -17.43 & -6.37 & 17.43 & 6.37 \end{pmatrix} + 10^3\begin{pmatrix} 0 & 0 & 0 & 0 \\ 0 & 553.98 & 0 & -553.98 \\ 0 & 0 & 0 & 0 \\ 0 & -553.98 & 0 & 553.98 \end{pmatrix}$$

$$K = 10^3\begin{pmatrix} 47.45 & 17.43 & -47.45 & -17.43 & 0 & 0 \\ 17.43 & 6.37 & -17.43 & 577.3 & 0 & 0 \\ -47.45 & -17.43 & 47.45 & 17.43 & 0 & 0 \\ -17.43 & -6.37 & 17.43 & 553.98 & 0 & -553.98 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & -553.98 & 0 & 553.98 \end{pmatrix}$$

$step5: global\ load\ factor$

$[F]=[K][q]$ since f1,f2,f3,f4,f5,q1,q2,q5 = 0.

$$\begin{pmatrix} 0 \\ 0 \\ -784.8 \end{pmatrix} = 10^3 \begin{pmatrix} 47.45 & 17.43 & 0 \\ 17.43 & -553.98 & -553.981 \\ 0 & -553.98 & 553.98 \end{pmatrix} \begin{bmatrix} q_3 \\ q_4 \\ q_6 \end{bmatrix}$$

$equations$

$$10^3\left(47.45q_3 + 17.43\mathrm{q}_4\right) = 0 \quad \rightarrow eq1$$

$$10^3(17.43q_3 + 553.98\mathrm{q}_4 - 553.98\mathrm{q}_6) = 0 \quad \rightarrow eq2$$

$$10^3(-553.98\mathrm{q}_4 + 553.98\mathrm{q}_6) = -784.8 \quad \rightarrow eq3$$

by solving the eq1, eq2, eq3

$q_3 =$ 0.041mm ,

$\mathrm{q}_6 = -0.112$mm,

$\mathrm{q}_4 = 0.3046$mm

$step6: results$

$$\sigma_1 = \frac{E}{l_e}[\text{-l -m l m}]\begin{bmatrix} q_1 \\ q_2 \\ q_3 \\ q_4 \end{bmatrix}$$

$$= \frac{120\times10^3}{250.05}[-0.93 \quad -0.34 \quad 0.93 \quad 0.34]\begin{bmatrix} 0 \\ 0 \\ 0.112 \\ 0.30 \end{bmatrix}$$

$$\sigma_1 = 98.85 N/mm^2 = 98.85\times10^7 Pa$$

$$\sigma_2 = \frac{E}{l_e}[\text{-l -m l m}]\begin{bmatrix} q_3 \\ q_4 \\ q_5 \\ q_6 \end{bmatrix}$$

$$= \frac{120\times10^3}{152.5}[0 \quad \text{-}0.998 \quad 0 \quad 0.998]\begin{bmatrix} 0.112 \\ 0.30 \\ 0 \\ 0.41 \end{bmatrix}$$

$$\sigma_2 = 0$$

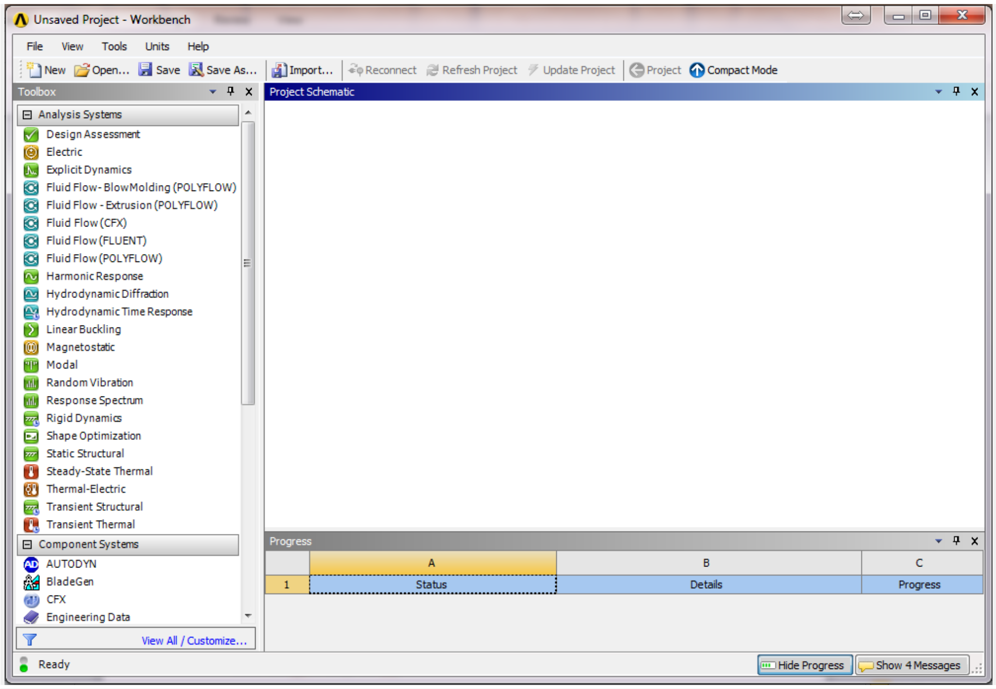
4. ANALYSIS

4.1 Ansys:

With the emerging importance of CFD and finite element analyses, it is of great necessity that engineering students get a good base of knowledge on one of the most used software packages in the industry of simulation, ANSYS.

ANSYS is a finite element analysis package used widely in industry to simulate the response of a physical system to structural loading, and thermal and electromagnetic effects. ANSYS uses the finite-element method to solve the underlying governing equations and the associated problem-specific boundary conditions.

FEM, A computer based analysis technique for calculating the strength and behavior of model during the given limits. In the FEM the model is represented as finite elements and is joined at special points which are called as nodes. Finite element analysis is the numerical solution of the mechanical components that are acquired by discretizing the mechanical elements into a small finite number of building blocks (known as elements) and by investigation those mechanical components for their acceptability and reliability. FEM is the simple technique as compared as the theoretical methods to discover the stress developed in a pair of gears. Models for numerical analysis have been prepared in SOLIDWORK and these have been bring in into ANSYS as IGES files for further analysis. The proportions of gear obtained from theoretical analysis have been used for preparing geometric model of gear. The condition for analysis has been assumed as static



This manual includes the procedure of solving the (static structural, Fluent) problems

Each one of the analysis systems has its own procedure. However, there are some common stages in all of the systems:

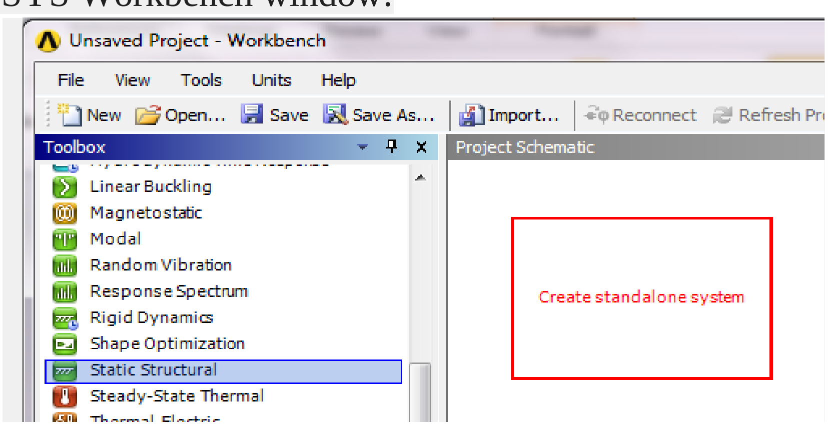
The ANSYS installation has many packages included. For this, we will be using ANSYS Workbench.

Start menu > ANSYS 15.0 > Workbench 15.0

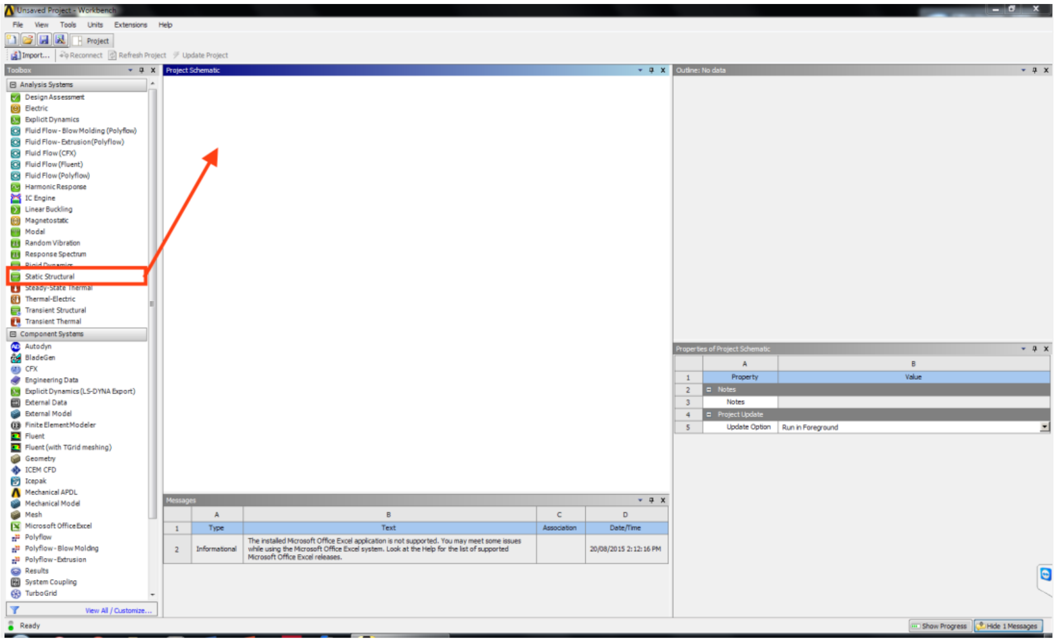
4.2 Steps:

4.2.1 Step1: Selection of Workbench

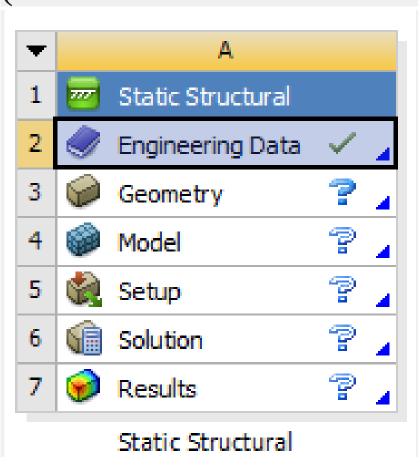
In ANSYS Workbench window:



- Drag (Static Structural) to the Project Schematic inside the red square

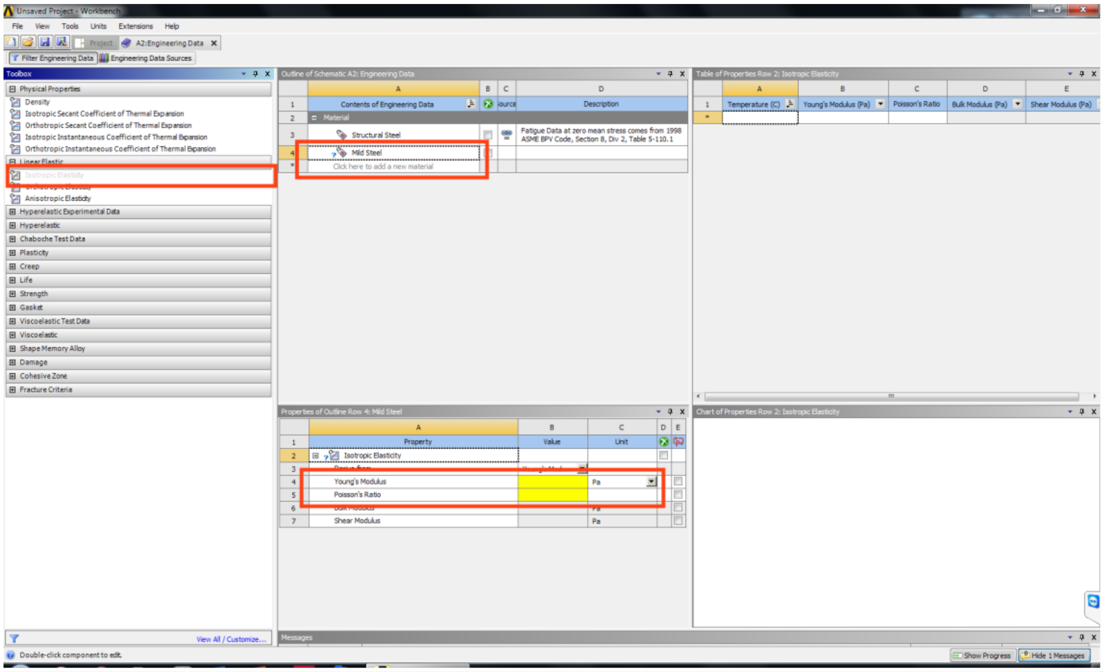


- Double Click on (Engineering Data) to configure and add the materials that would be used in the analysis along with their properties.
- ** The shown window will appear where a new material can be added >> (click here to add a new material)>> add (material for the beam)



4.2.2 Step 2: Engineering Data

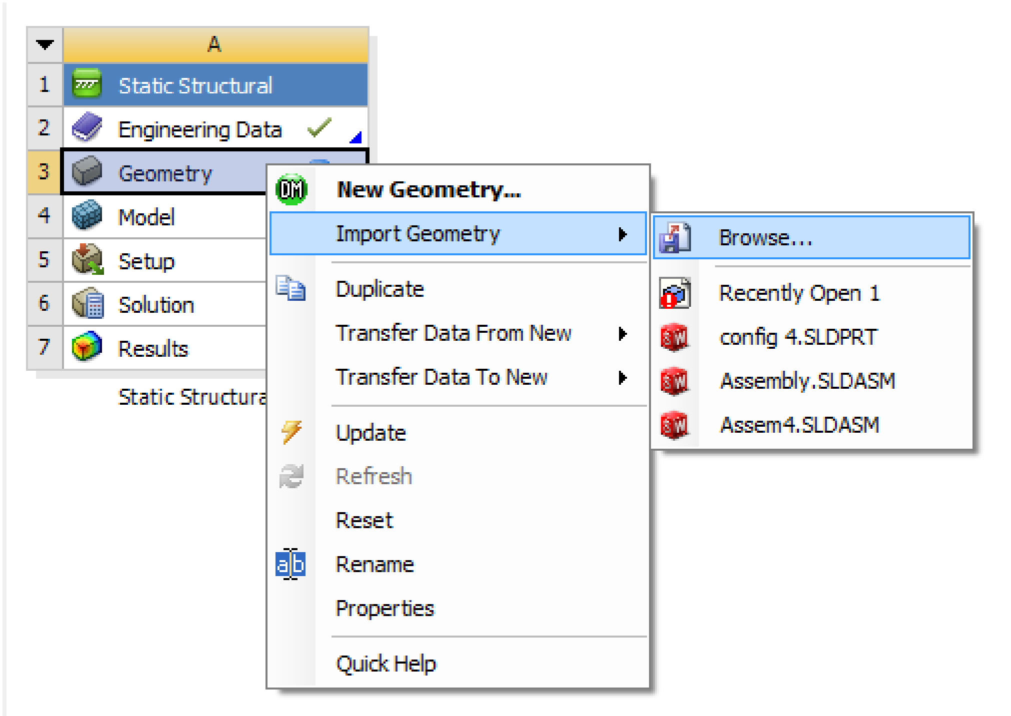
- Double--click Engineering Data. What you see in this window may differ from the screenshot below. In here, you can add a new material by defining a new material entry for Mild Steel. We want to define the material as an isotropic elastic one.



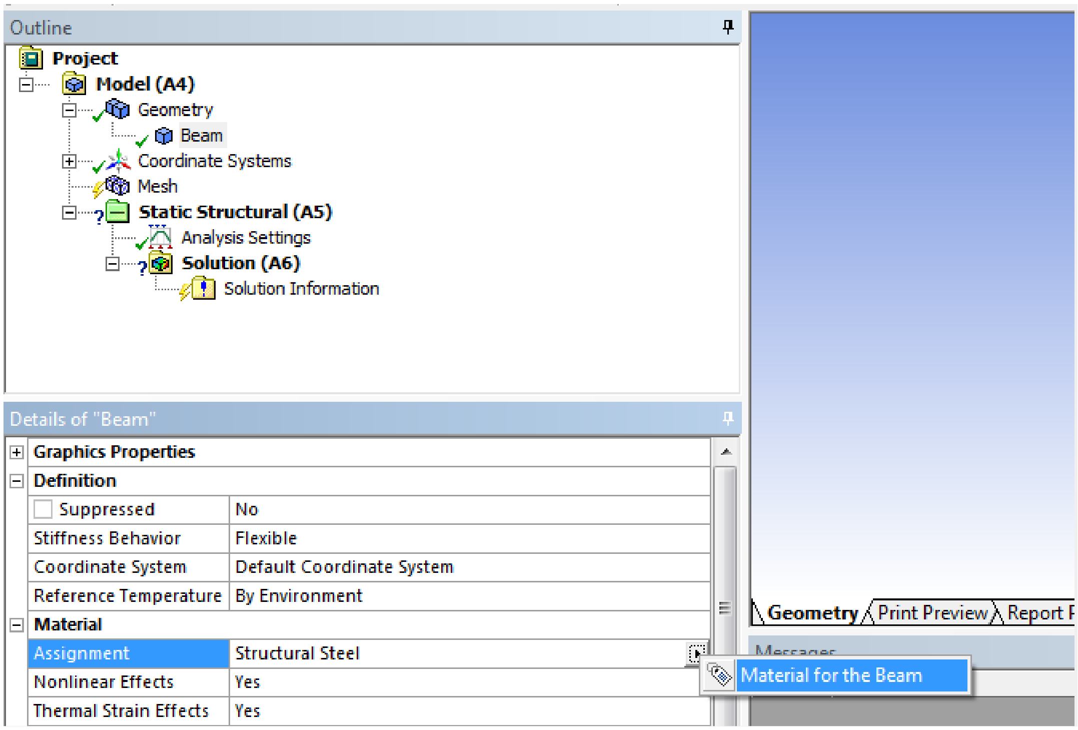
- In the Toolbox, the material properties can be added from “Density” or “Isotropic Elasticity”. Double Clicking on the mentioned options will open new fields in the outline where the fields have to be filled with the values of the properties.
- Note: Try to find the desired material in the “Engineering Data Source” Library before adding a new material. Click on the icon >> select the type of the material and the materials will appear in a list. If you want to add a material to your project list, click on After you are done with adding all the materials needed in the project, click on “Return to Project”
- The Engineering Data field should be marked with a indicating that the process of adding materials properties has been done.

4.2.3 Step 3: Geometry

- ** Right Click on (Geometry) >> Import Geometry >> Browse >> Locate the geometry file
- Note: Simple geometry can be constructed in Ansys Geometry window itself. However, complex geometry should be imported from 3D modeling software like Solidworks, as it has been done in this exercise.

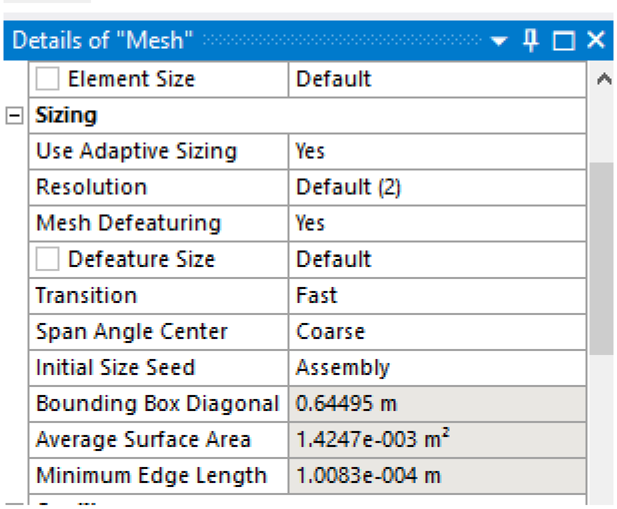


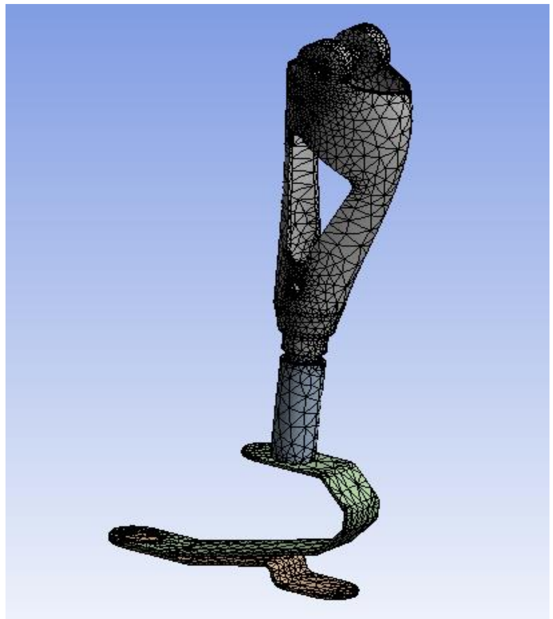
- On the Tree Outline on the left side >> Right Click on "Import" >> Generate. Hence, the geometry will appear in the graphics window. After this step, close the geometry window.
- Double click on "Model"
- On the outline window, expand the "Geometry" tree by clicking on "+", this tree should show you all the parts in the project (will be clear when there are multiple parts in the project). Moreover, the tree helps in assigning different material to different parts or managing the contact type between two parts (Frictional, Frictionless, etc).



4.2.4 Step 4: Mesh generation :

In the analysis of the gear assembly it is mandatory to study of its structural behavior at different load and condition. 3–D model of the gear assembly were made in solidwork and were carried out in ansys analysis software as an iges file format . thereafter importing the model in ansys the suitable material was applied to the model and then meshing were done in ansys by which the whole body is divided into small tetrahedral element connected by nodes



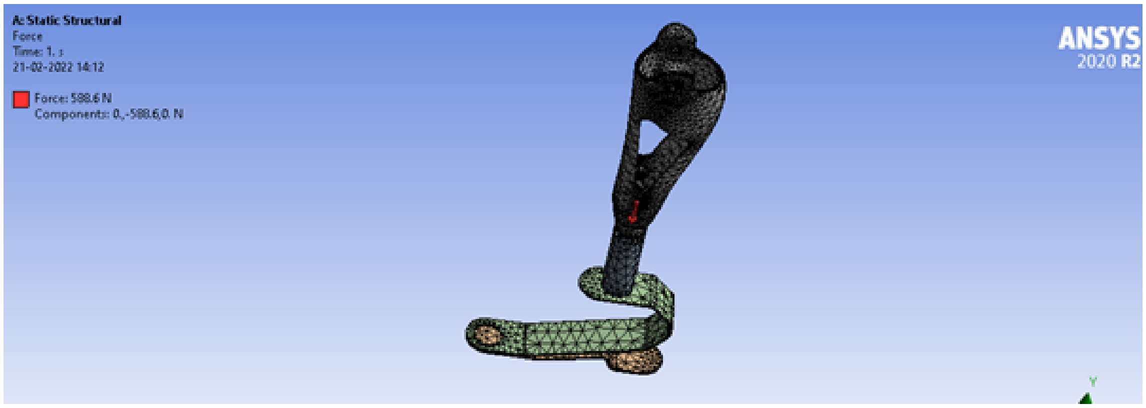


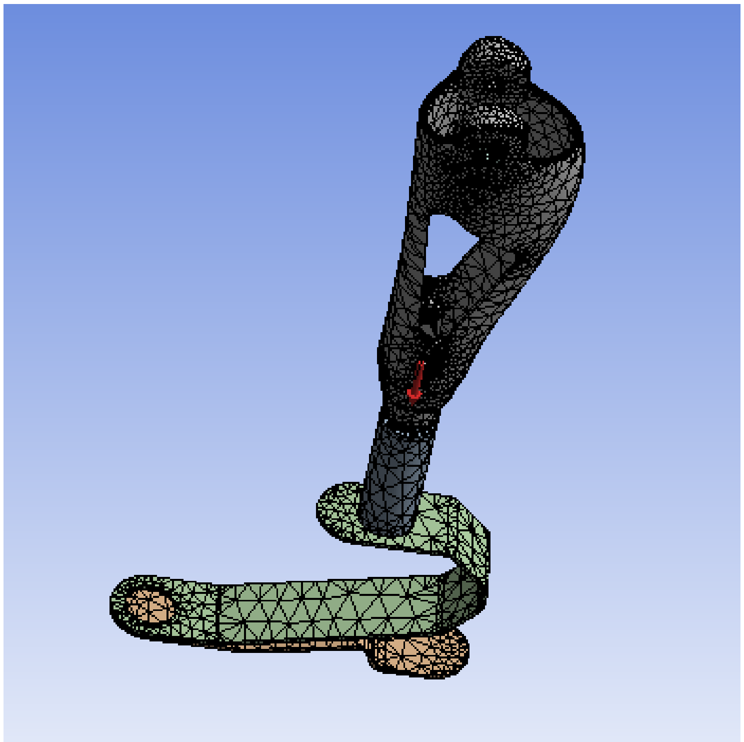
Steps:

- On the outline window, click on “Mesh”. For generating the mesh with the default size, click on from the top bars. For advanced mesh options, adjust the settings from “Details of Mesh” window.
- Note: The default mesh is usually a very basic grid with no attention given to the details of the geometry. Advanced mesh details can be added by choosing the geometrical detail and inserting “sizing” as it is shown in the figure. The details can be chosen using the selecting icons.

4.2.5 Step 5: Adding forces:

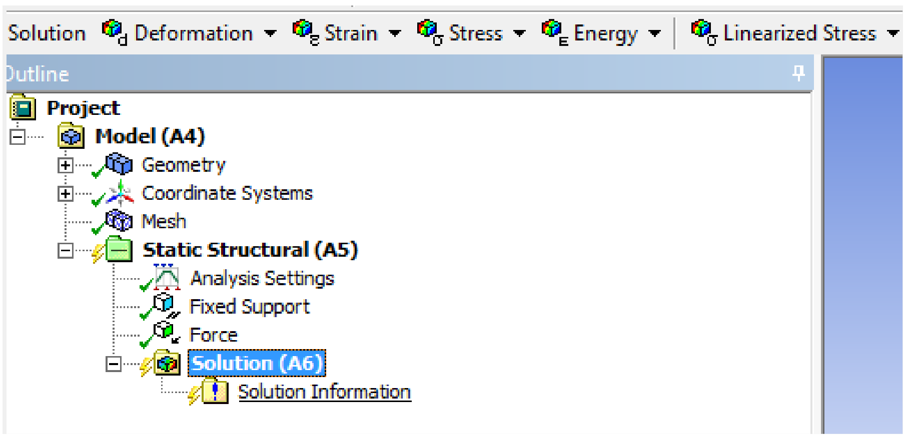
- Add the force from the "Loads" list. In the "Details of Force" window, change "Defined By" to "Components" and then set the "Y" direction force to be "–588.6N"





4.2.6 Step 6: Solution :

1. To define the desired solution parameters, click on "Solutions" and define all the parameters needed to be found. The parameters can be chosen from the lists shown in the figure.
2. After defining the investigation parameters, click to get the results. To show the results of the different parameters, use the list under "solutions" in the "Outline" window.



.

Al Alloy:

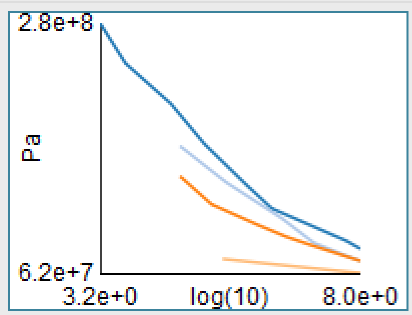
Aluminum Alloy

General aluminum alloy. Fatigue properties come from MIL-HDBK-5H, page 3-277.

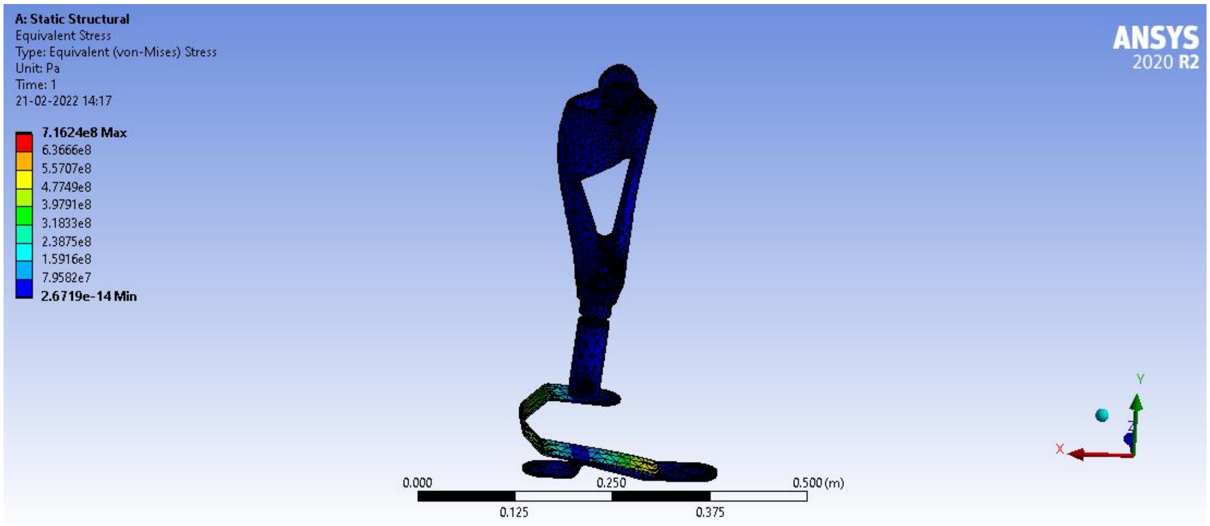
Density	2770 kg/m³

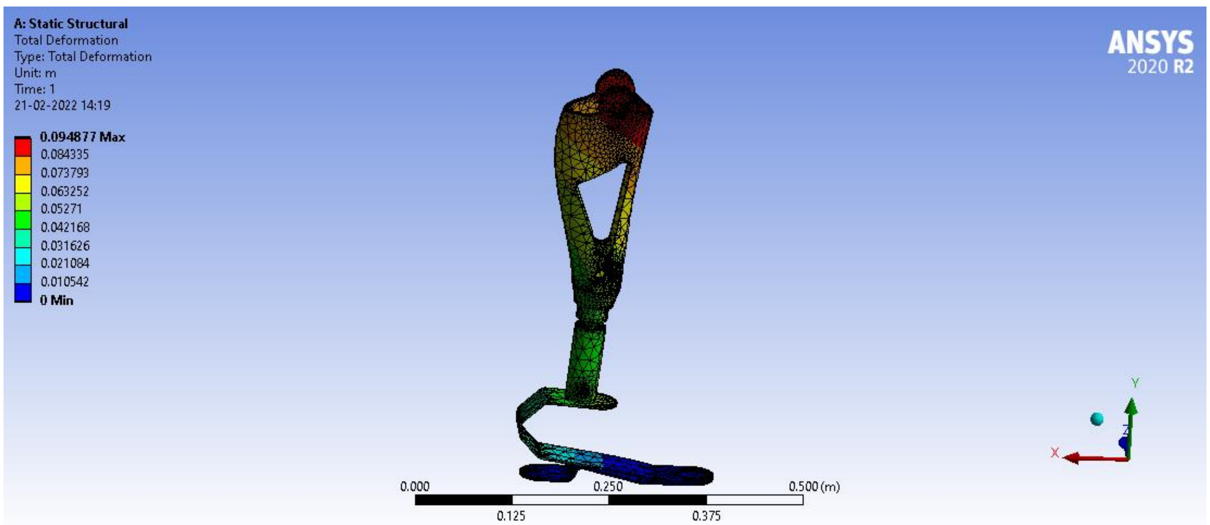
Structural

Isotropic Elasticity

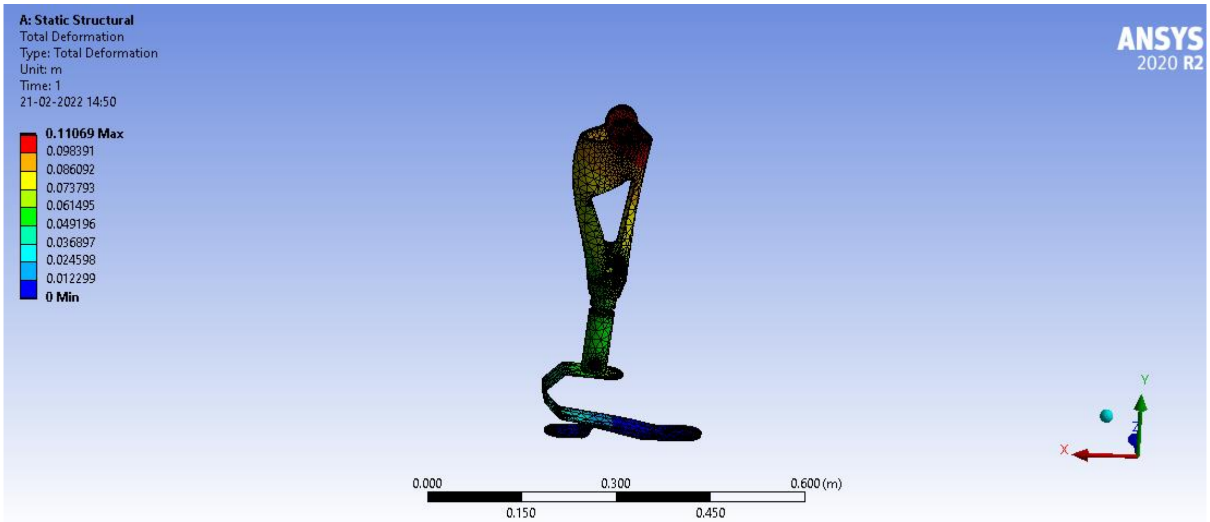
Derive from	Young's Modulus and Poisson's Ratio
Young's Modulus	7.1e+10 Pa
Poisson's Ratio	0.33
Bulk Modulus	6.9608e+10 Pa
Shear Modulus	2.6692e+10 Pa
Isotropic Secant Coefficient of Thermal Expansion	2.3e-05 1/°C
Compressive Ultimate Strength	0 Pa
Compressive Yield Strength	2.8e+08 Pa
S-N Curve	
Tensile Ultimate Strength	3.1e+08 Pa
Tensile Yield Strength	2.8e+08 Pa

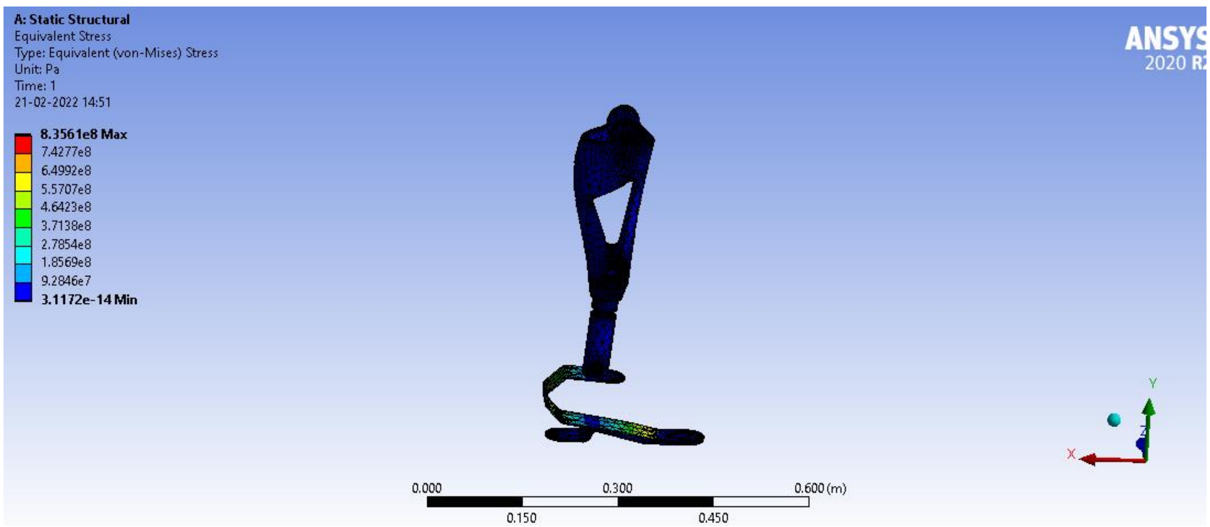
Aluminium Alloy Load 60 Kg = 588.6N



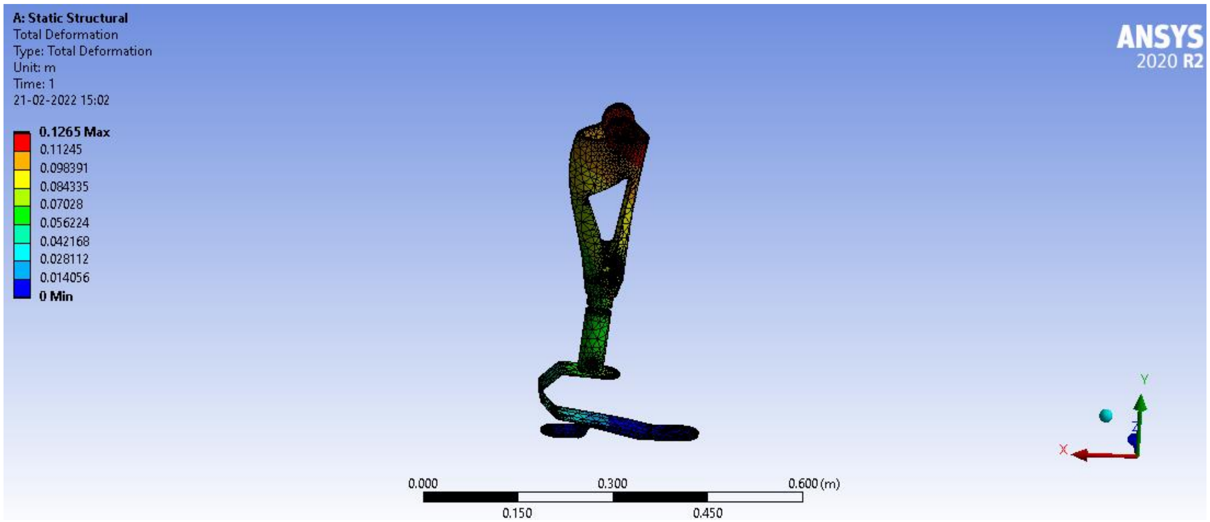


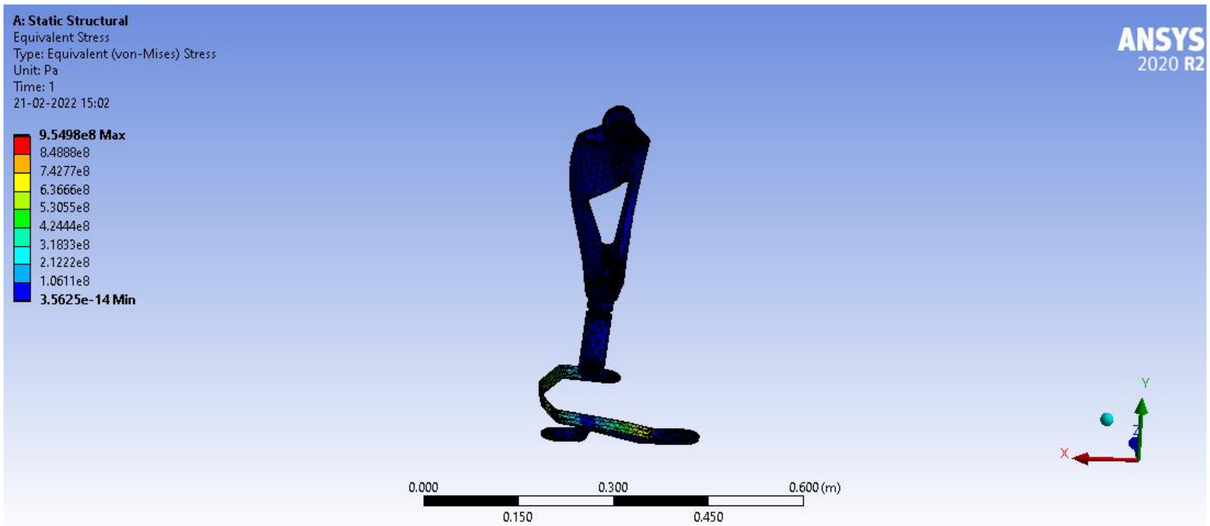
Aluminium alloy Load 70 Kg = 686.7N



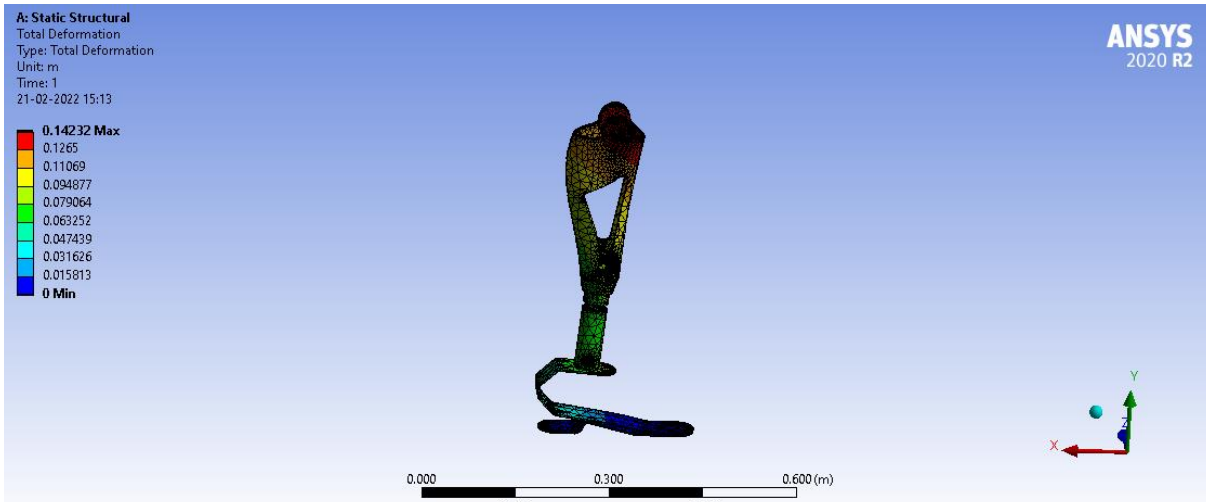


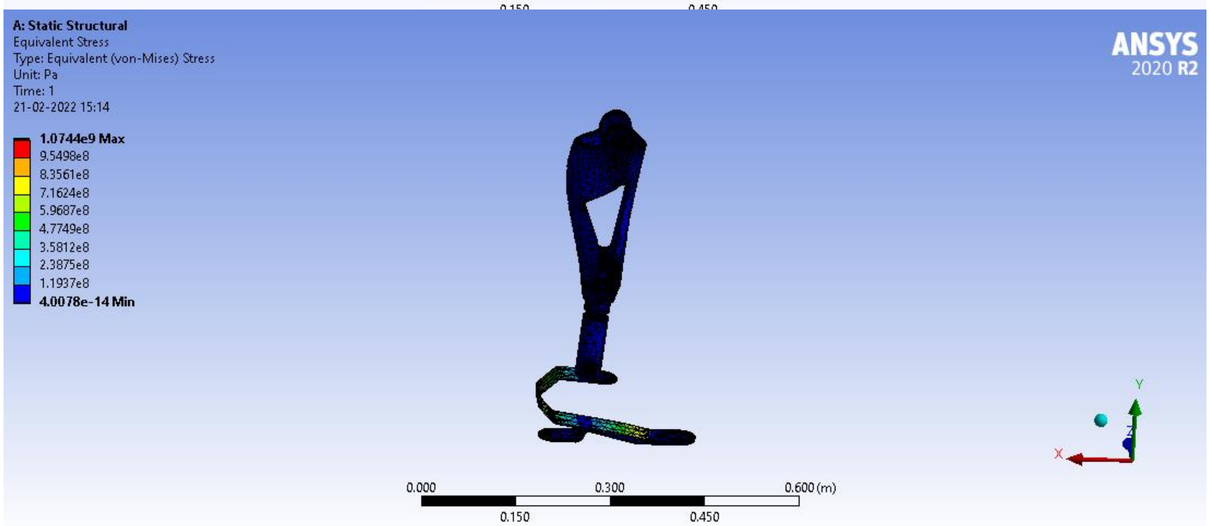
Aluminium Alloy Load = 80 Kg = 784.8N





Aluminium Alloy Load 90 kg = 882.9 N


A: Static Structural
Total Deformation
Type: Total Deformation
Unit: m
Time: 1
21-02-2022 15:13
0.14232 Max
0.1265
0.11069
0.094877
0.079064
0.063252
0.047439
0.031626
0.015813
0 Min
ANSYS
2020 R2
0.000
0.300
0.600 (m)
Y
X


A: Static Structural
Equivalent Stress
Type: Equivalent (von-Mises) Stress
Unit: Pa
Time: 1
21-02-2022 15:14
1.0744e9 Max
9.5498e8
8.3561e8
7.1624e8
5.9687e8
4.7749e8
3.5812e8
2.3875e8
1.1937e8
4.0078e-14 Min
ANSYS
2020 R2
0.000
0.300
0.600 (m)
0.150
0.450
Y
X

Ti Alloy

Titanium Alloy

Density	4620 kg/m³

Structural

Isotropic Elasticity

Derive from	Young's Modulus and Poisson's Ratio
Young's Modulus	9.6e+10 Pa
Poisson's Ratio	0.36
Bulk Modulus	1.1429e+11 Pa
Shear Modulus	3.5294e+10 Pa
Isotropic Secant Coefficient of Thermal Expansion	9.4e-06 1/°C
Compressive Ultimate Strength	0 Pa
Compressive Yield Strength	9.3e+08 Pa
Tensile Ultimate Strength	1.07e+09 Pa
Tensile Yield Strength	9.3e+08 Pa

Thermal

Isotropic Thermal Conductivity	21.9 W/m·°C
Specific Heat Constant Pressure	522 J/kg·°C

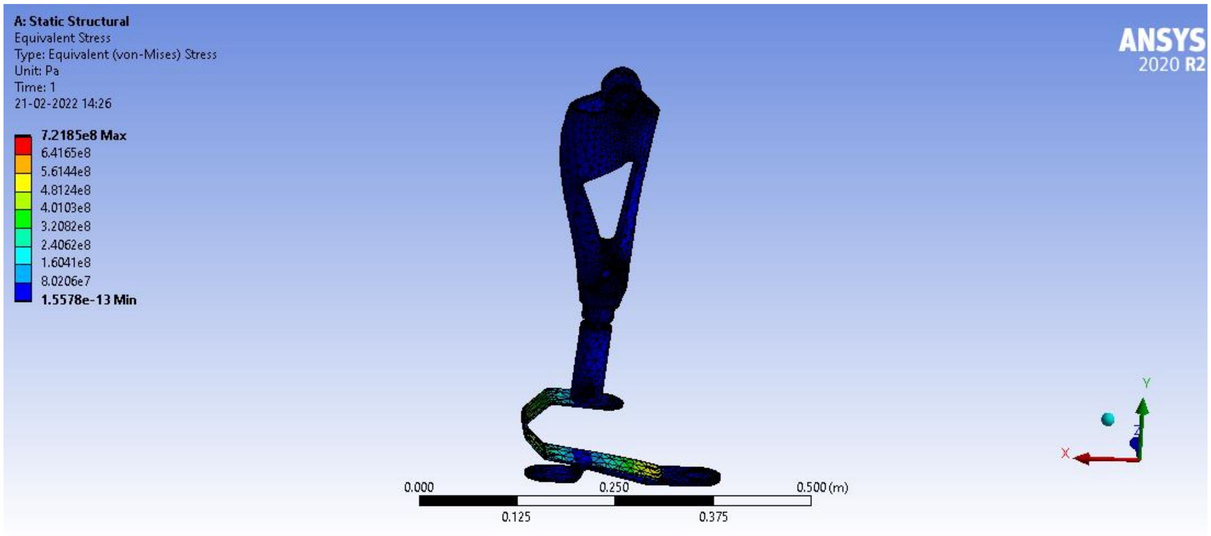
Electric

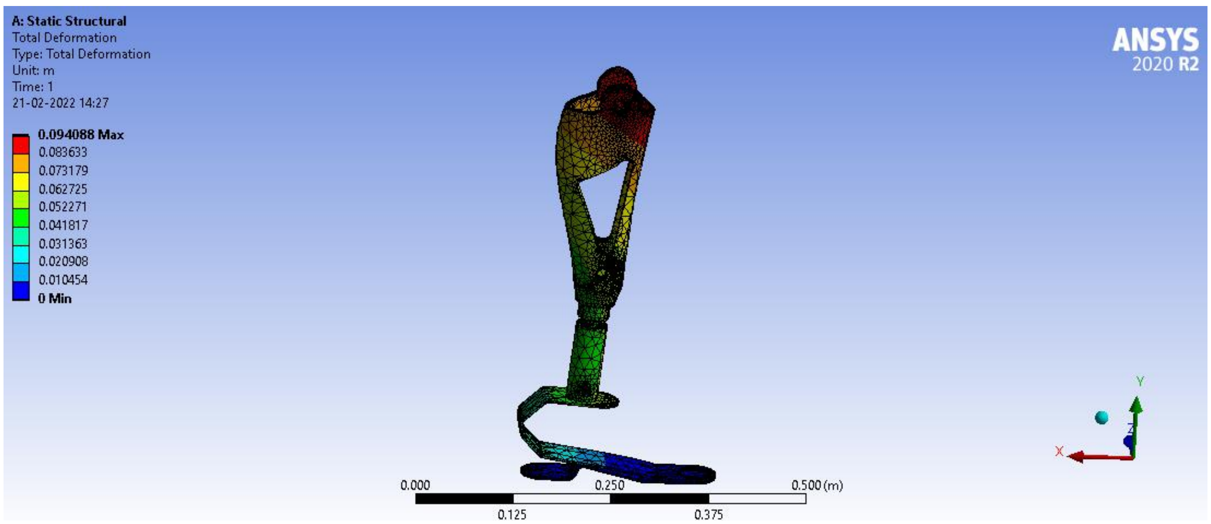
Isotropic Resistivity	1.7e-06 ohm·m

Magnetic

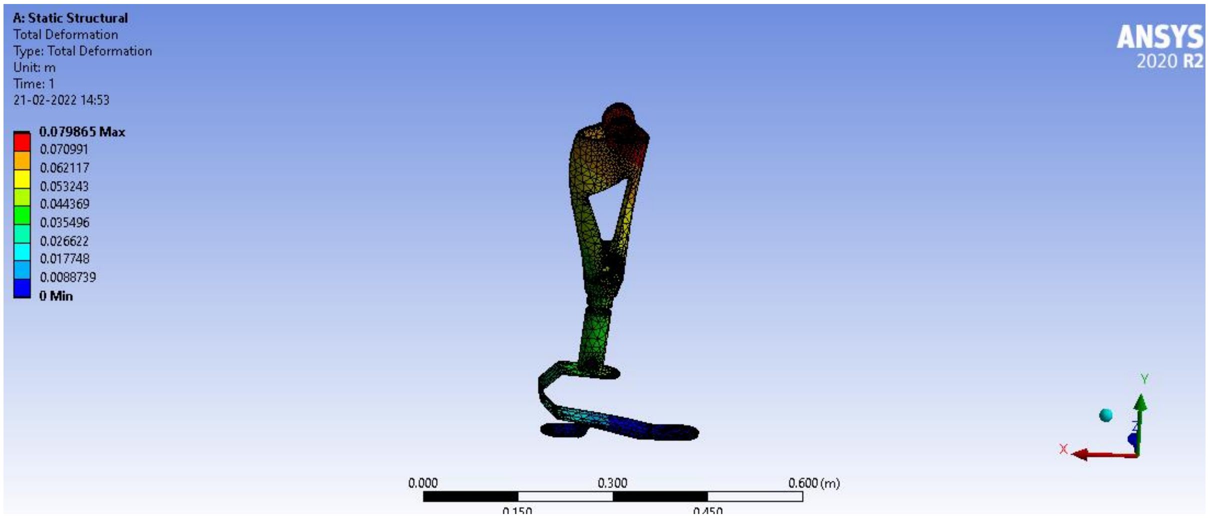
Isotropic Relative Permeability	1

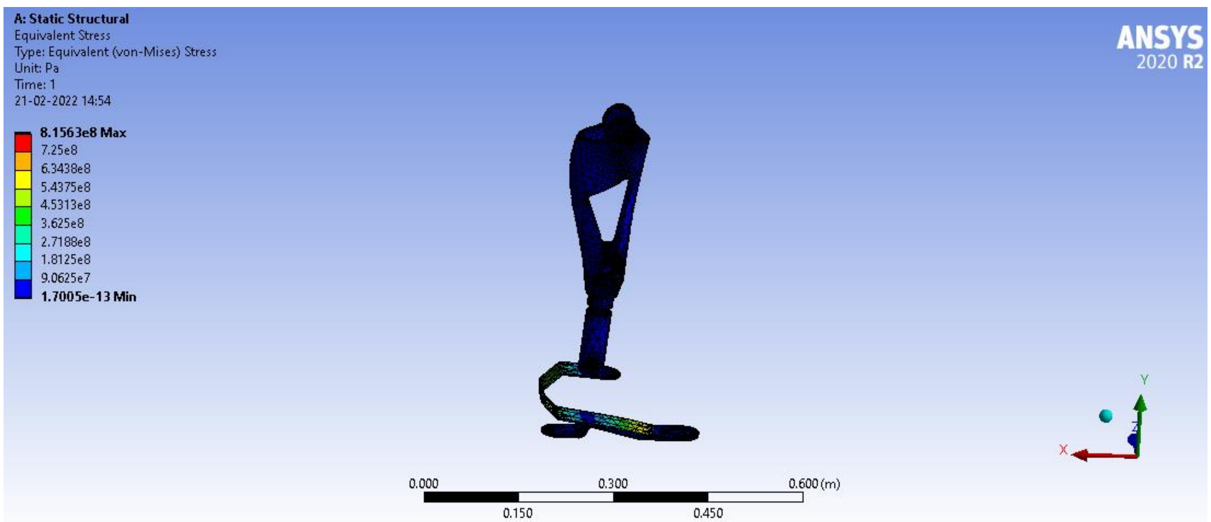
Titanium Alloy Load 60 Kg = 588.6N



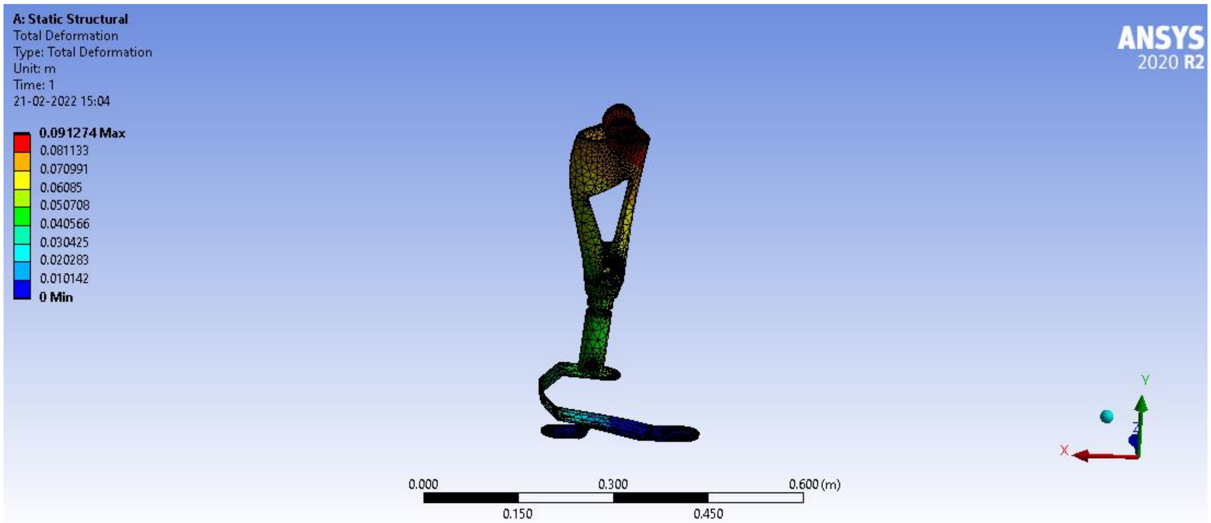


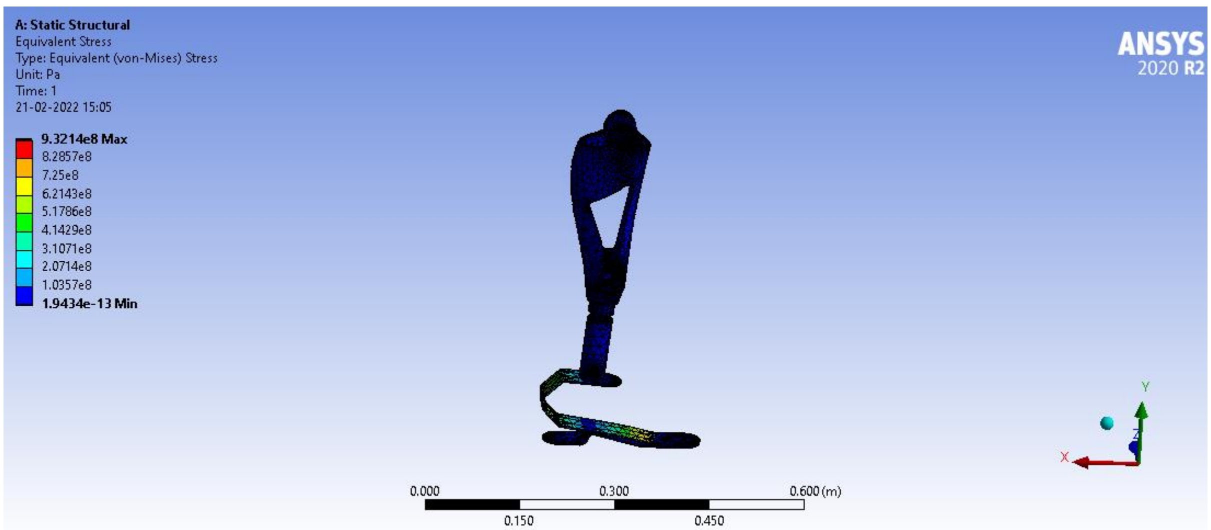
a) Titanium Alloy



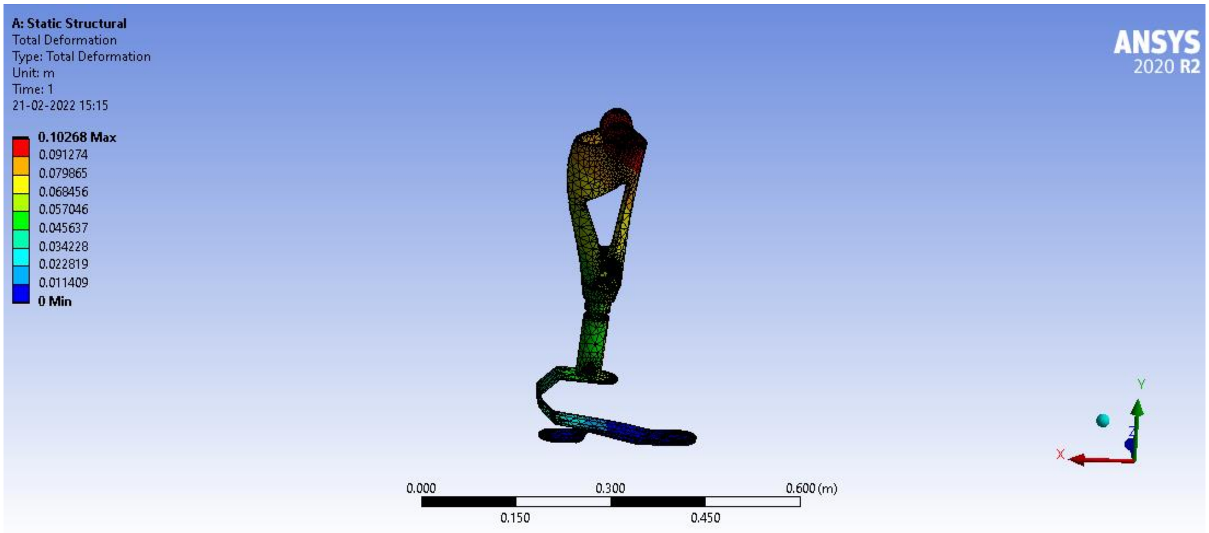


Titanium Alloy Load = 80 Kg = 784.8N

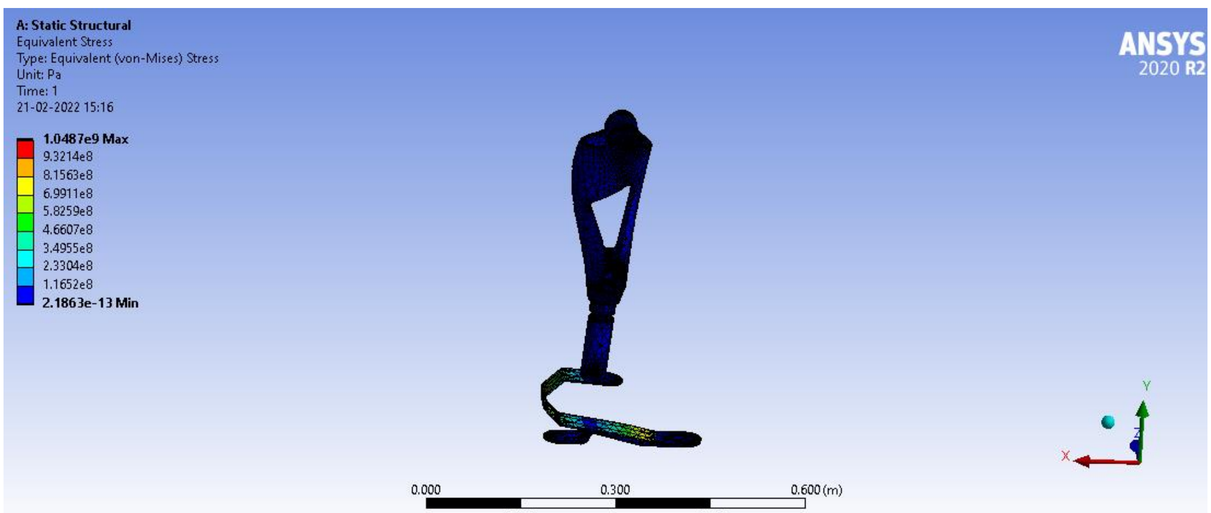




Titanium Alloy Load 90 kg = 882.9 N



A: Static Structural
Total Deformation
Type: Total Deformation
Unit: m
Time: 1
21-02-2022 15:15
0.10268 Max
0.091274
0.079865
0.068456
0.057046
0.045637
0.034228
0.022819
0.011409
0 Min
ANSYS
2020 R2
0.000
0.300
0.600 (m)
0.150
0.450



A: Static Structural
Equivalent Stress
Type: Equivalent (von-Mises) Stress
Unit: Pa
Time: 1
21-02-2022 15:16
1.0487e9 Max
9.3214e8
8.1563e8
6.9911e8
5.8259e8
4.6607e8
3.4955e8
2.3304e8
1.1652e8
2.1863e-13 Min
ANSYS
2020 R2
0.000
0.300
0.600 (m)

Carbon Fiber Epoxy

Epoxy Carbon UD (395 GPa) ...

Density	1540 kg/m^3

Structural

Orthotropic Elasticity

Young's Modulus X direction	2.09e+11 Pa
Young's Modulus Y direction	9.45e+09 Pa
Young's Modulus Z direction	9.45e+09 Pa
Poisson's Ratio XY	0.27
Poisson's Ratio YZ	0.4
Poisson's Ratio XZ	0.27
Shear Modulus XY	5.5e+09 Pa
Shear Modulus YZ	3.9e+09 Pa
Shear Modulus XZ	5.5e+09 Pa

Orthotropic Stress Limits

Tensile X direction	1.979e+09 Pa
Tensile Y direction	2.6e+07 Pa
Tensile Z direction	2.6e+07 Pa
Compressive X direction	-8.93e+08 Pa
Compressive Y direction	-1.39e+08 Pa
Compressive Z direction	-1.39e+08 Pa
Shear XY	1e+08 Pa
Shear YZ	5e+07 Pa
Shear XZ	1e+08 Pa

Orthotropic Strain Limits

Tensile X direction	0.0092
Tensile Y direction	0.0031
Tensile Z direction	0.0031
Compressive X direction	-0.0053
Compressive Y direction	-0.0172
Compressive Z direction	-0.0172
Shear XY	0.016
Shear YZ	0.014
Shear XZ	0.016

Tsai-Wu Constants

Coupling Coefficient XY	-1
Coupling Coefficient YZ	-1
Coupling Coefficient XZ	-1

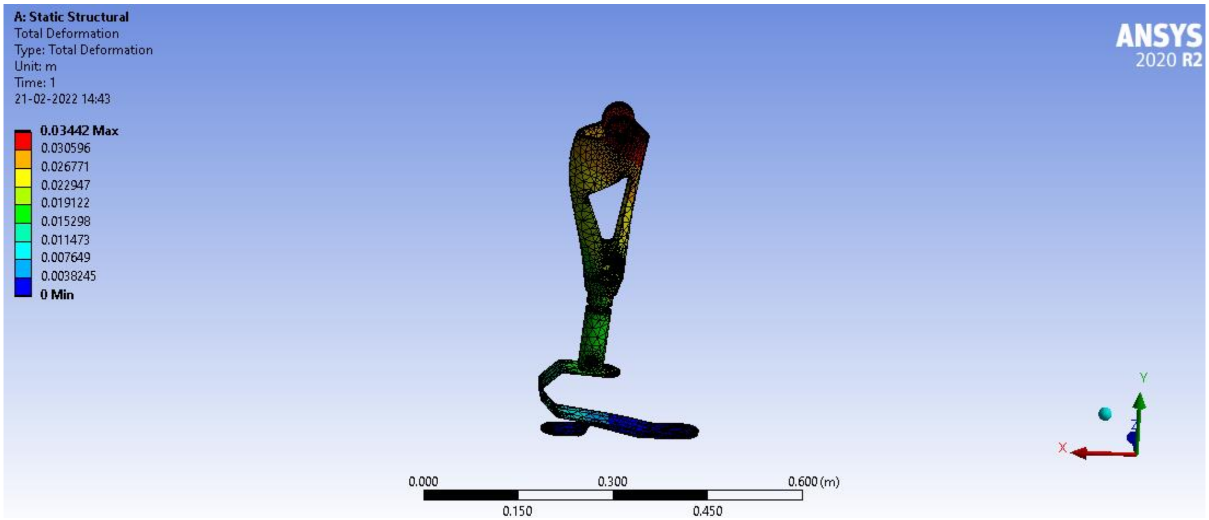
Puck Constants

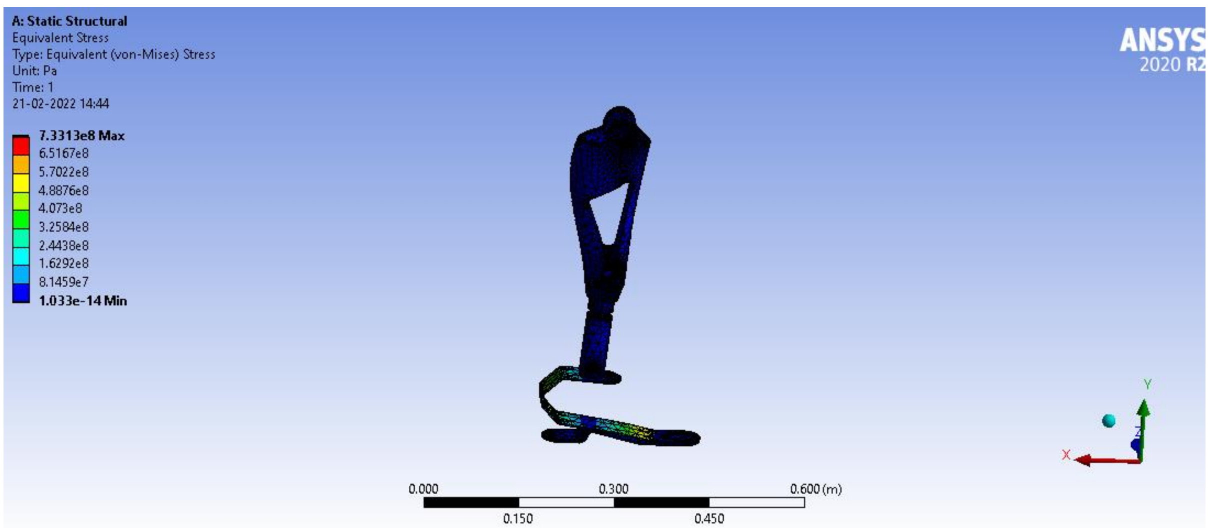
Material Classification	Carbon
Compressive Inclination XZ	0.3
Compressive Inclination YZ	0.25
Tensile Inclination XZ	0.35
Tensile Inclination YZ	0.25

Orthotropic Secant Coefficient of Thermal Expansion

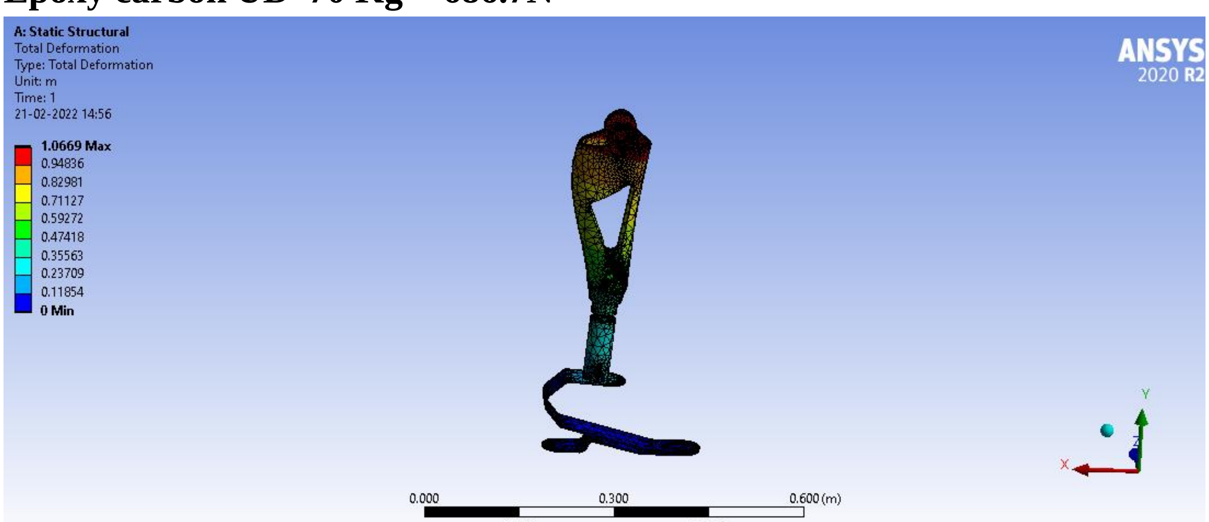
Coefficient of Thermal Expansion X direction	-4e-07 1/°C
Coefficient of Thermal Expansion Y direction	3e-05 1/°C
Coefficient of Thermal Expansion Z direction	3e-05 1/°C

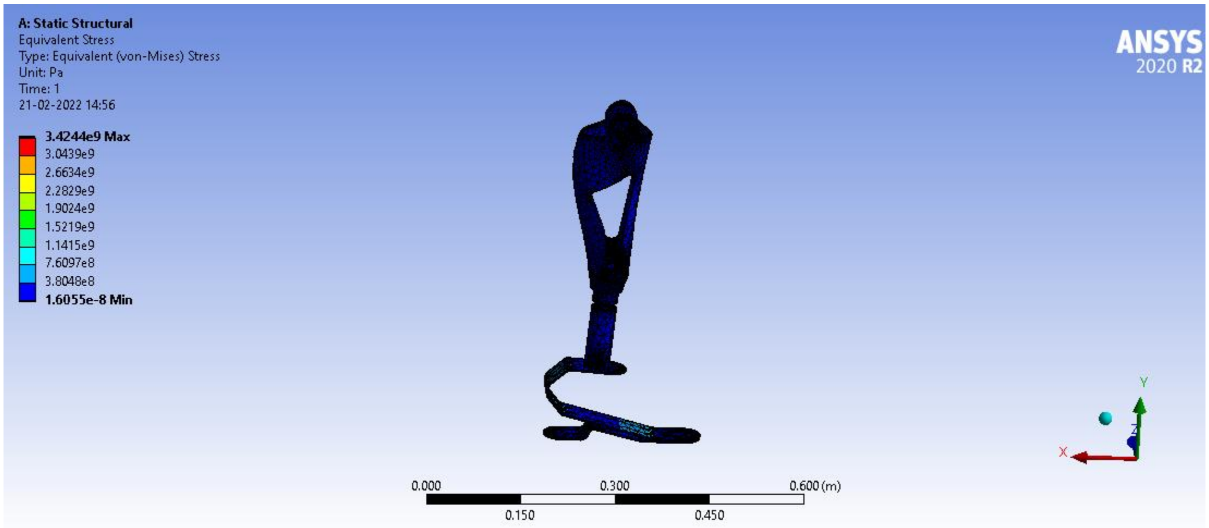
Carbon fiber Epoxy Load 60 Kg = 588.6N



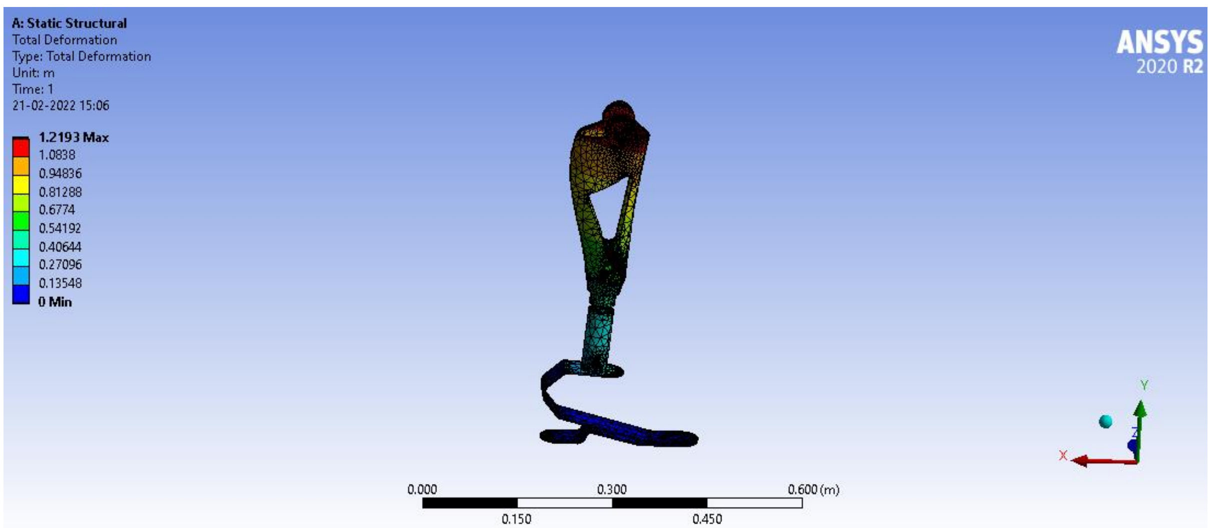


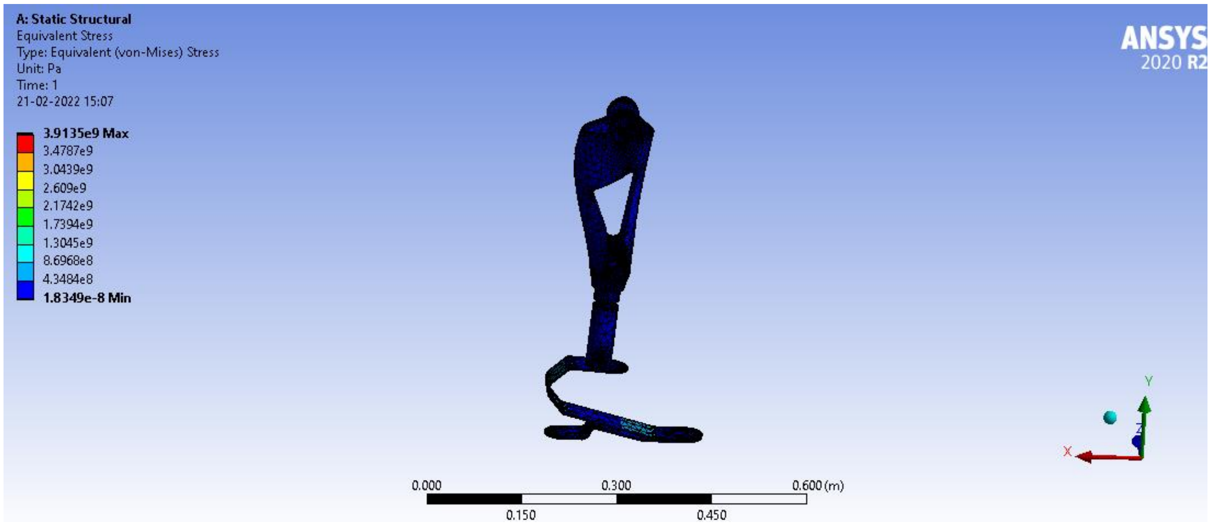
Epoxy carbon UD 70 Kg = 686.7N



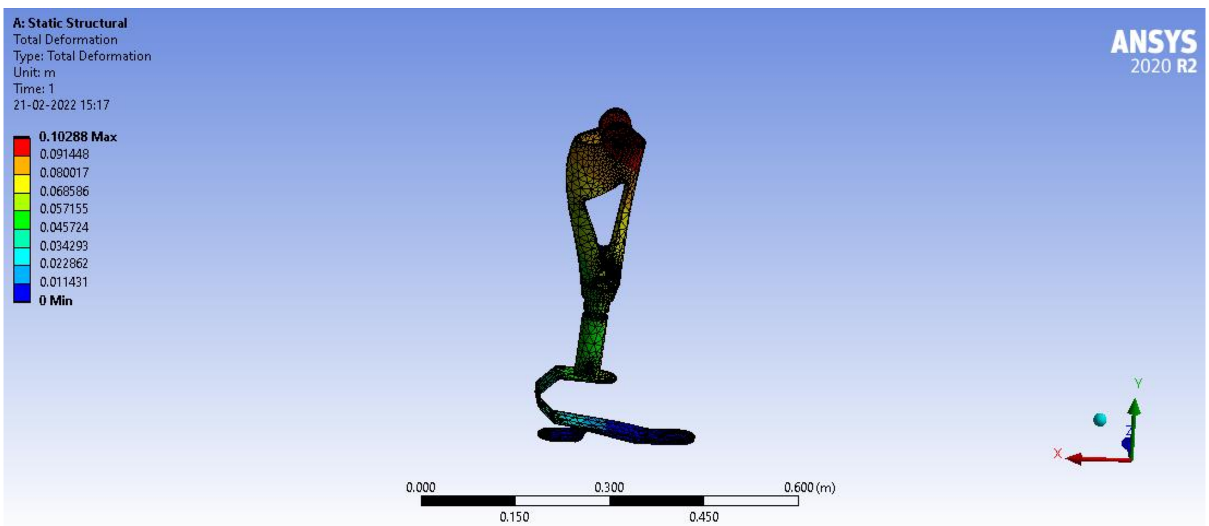


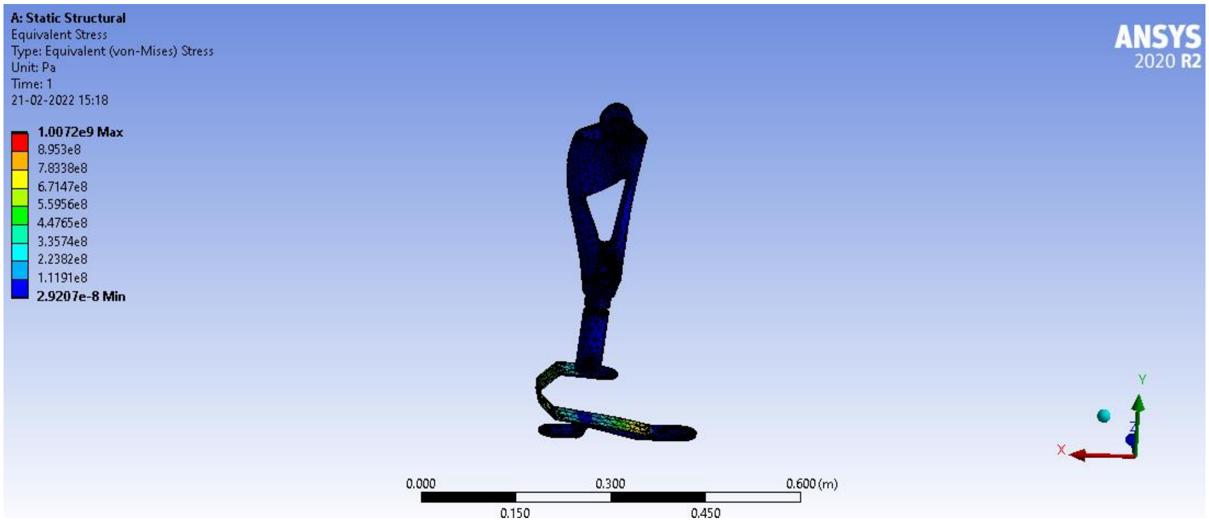
Epoxy carbon UD Load = 80 Kg = 784.8N





Cabon fiber – Epoxy UD Load 90 kg = 882.9 N





A: Static Structural
Equivalent Stress
Type: Equivalent (von-Mises) Stress
Unit: Pa
Time: 1
21-02-2022 15:18
1.0072e9 Max
8.953e8
7.8338e8
6.7147e8
5.5956e8
4.4765e8
3.3574e8
2.2382e8
1.1191e8
2.9207e-8 Min
ANSYS
2020 R2
0.000
0.300
0.600 (m)
0.150
0.450
Y
X
Z

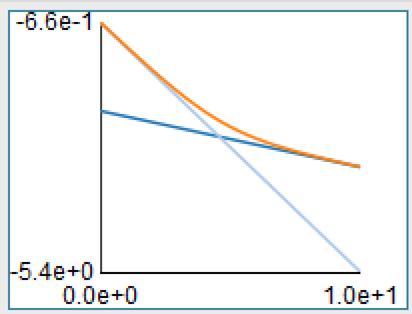
Structural Steel

Fatigue Data at zero mean stress comes from 1998 ASME BPV Code, Section 8, Div 2, Table 5-110.1

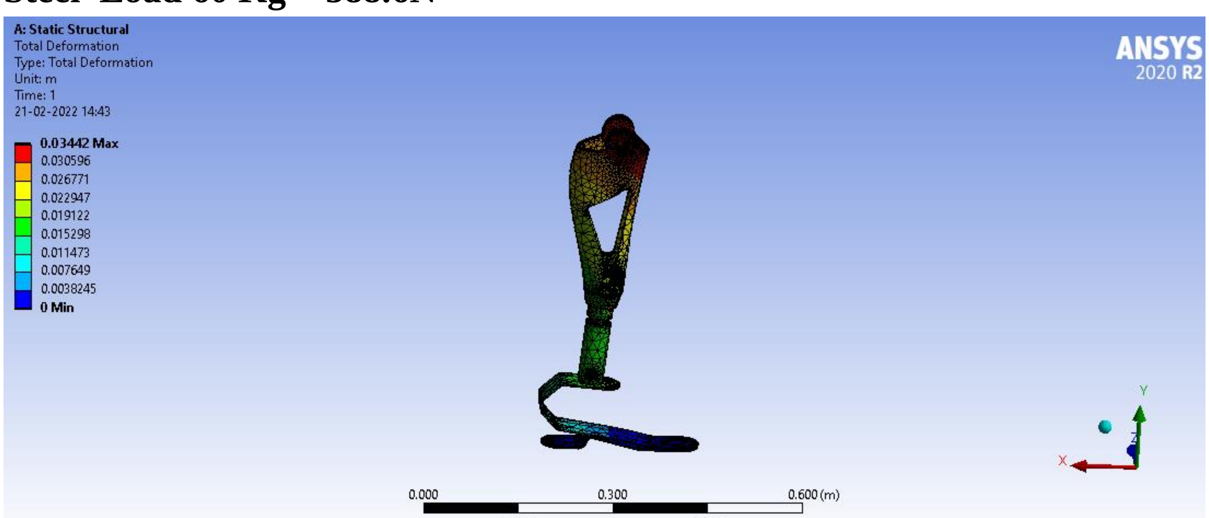
Density	7850 kg/m³

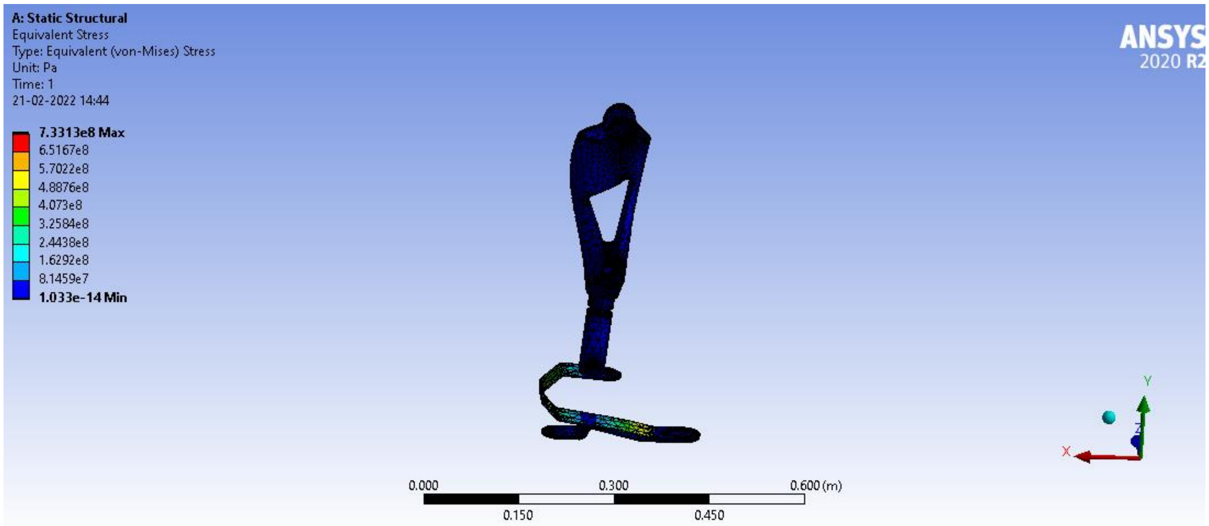
Structural

Isotropic Elasticity

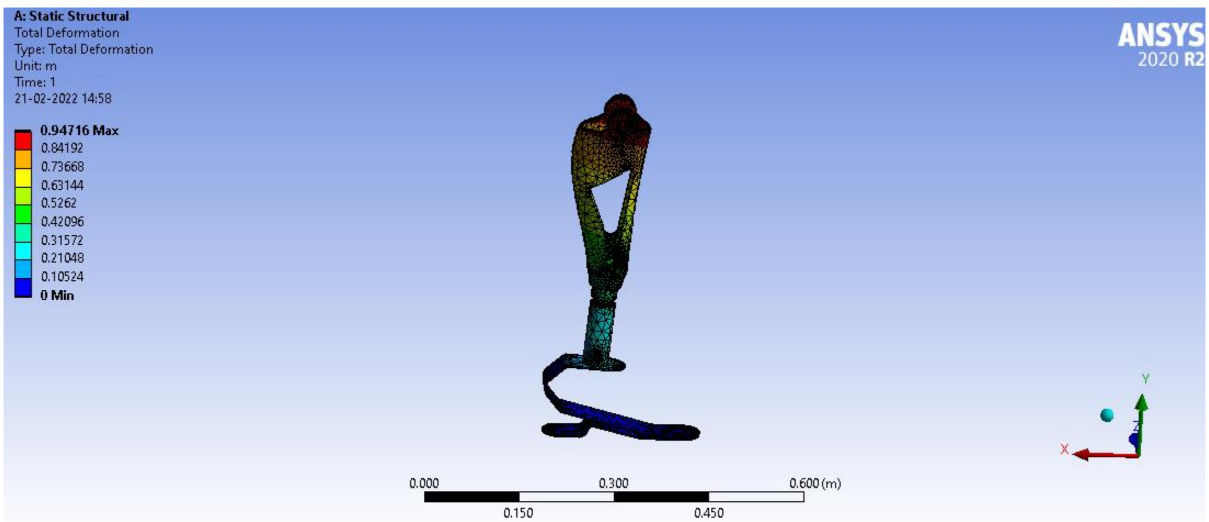
Derive from	Young's Modulus and Poisson's Ratio
Young's Modulus	2e+11 Pa
Poisson's Ratio	0.3
Bulk Modulus	1.6667e+11 Pa
Shear Modulus	7.6923e+10 Pa
Isotropic Secant Coefficient of Thermal Expansion	1.2e-05 1/°C
Compressive Ultimate Strength	0 Pa
Compressive Yield Strength	2.5e+08 Pa
Strain-Life Parameters	

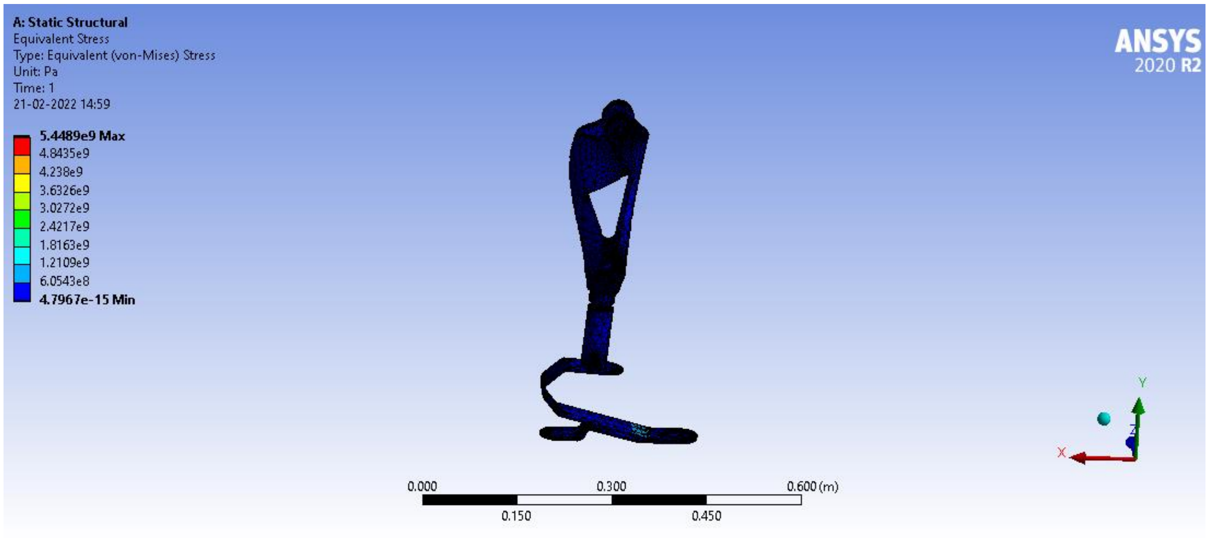
Steel Load 60 Kg = 588.6N



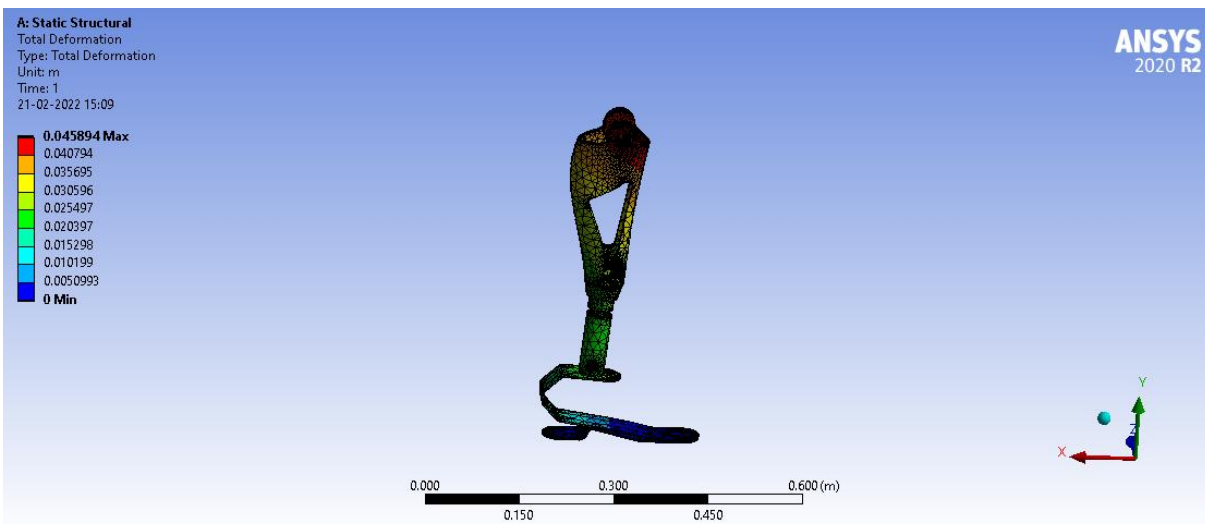


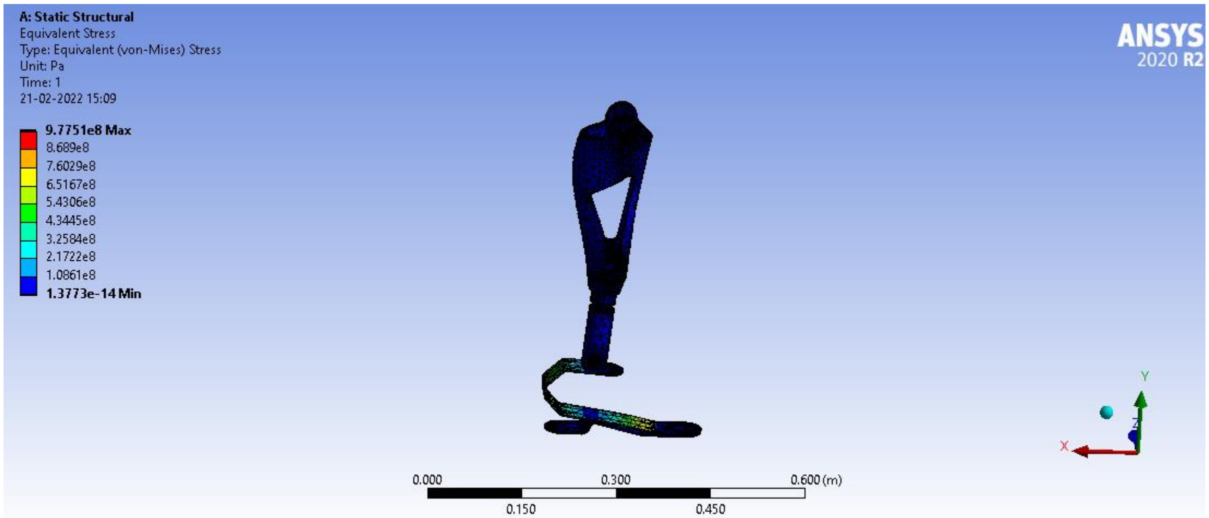
Structural steel 70 Kg = 686.7N



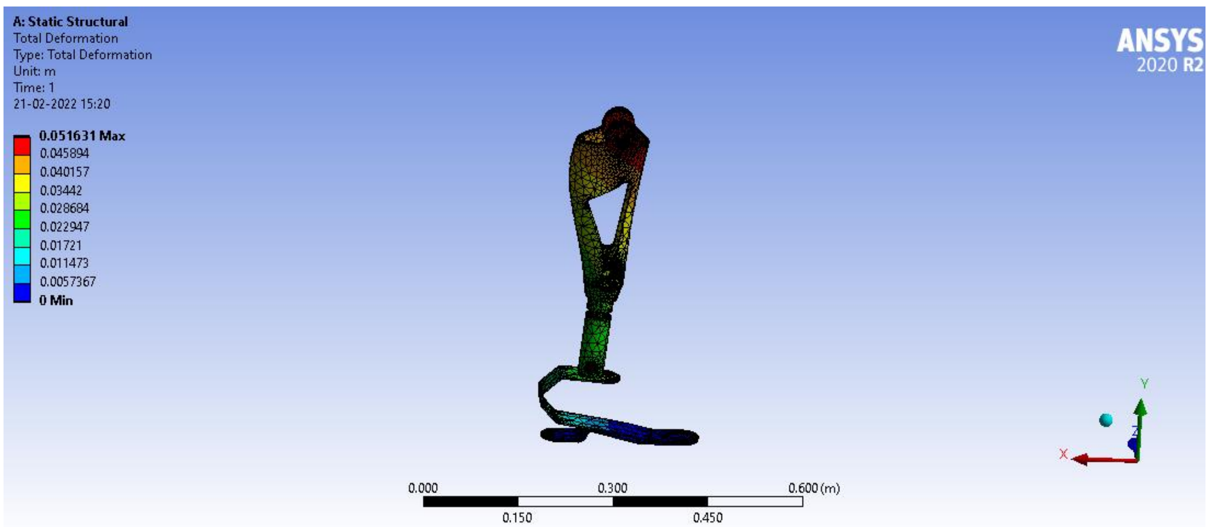


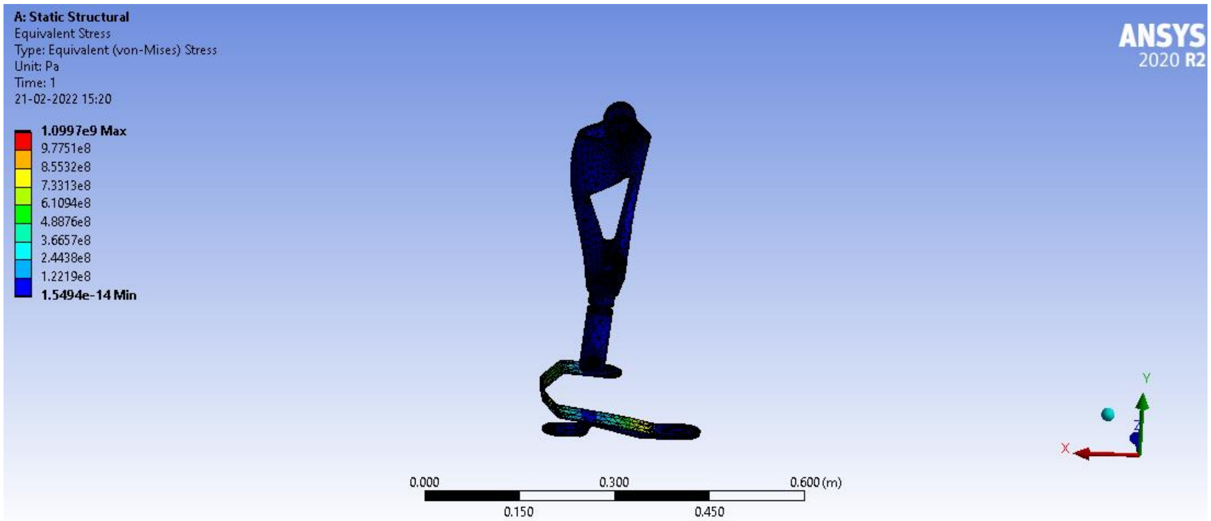
Structural steel Load = 80 Kg = 784.8N





Structural steel Load 90 kg = 882.9 N



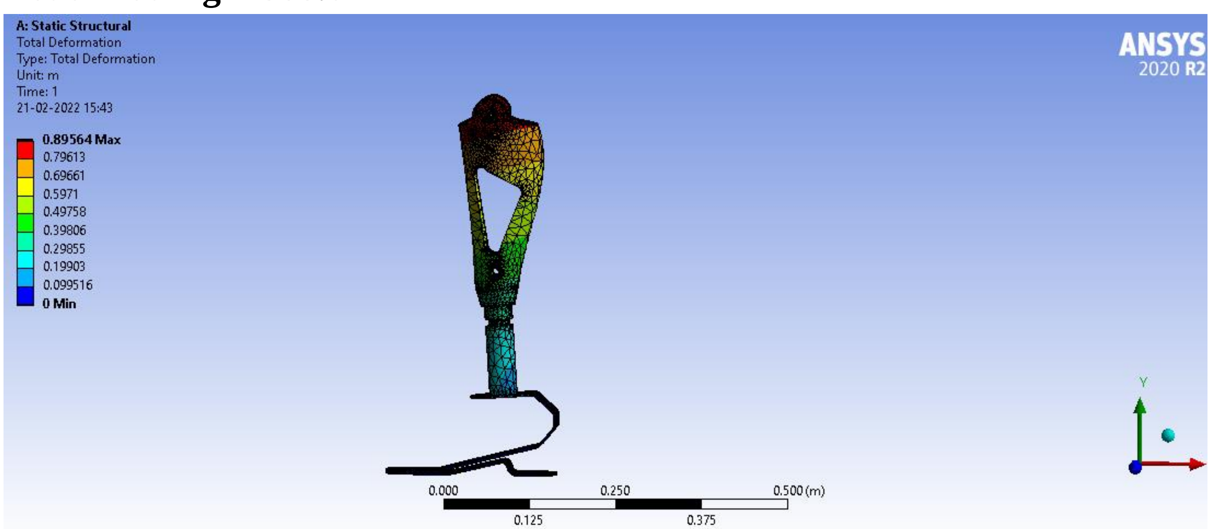


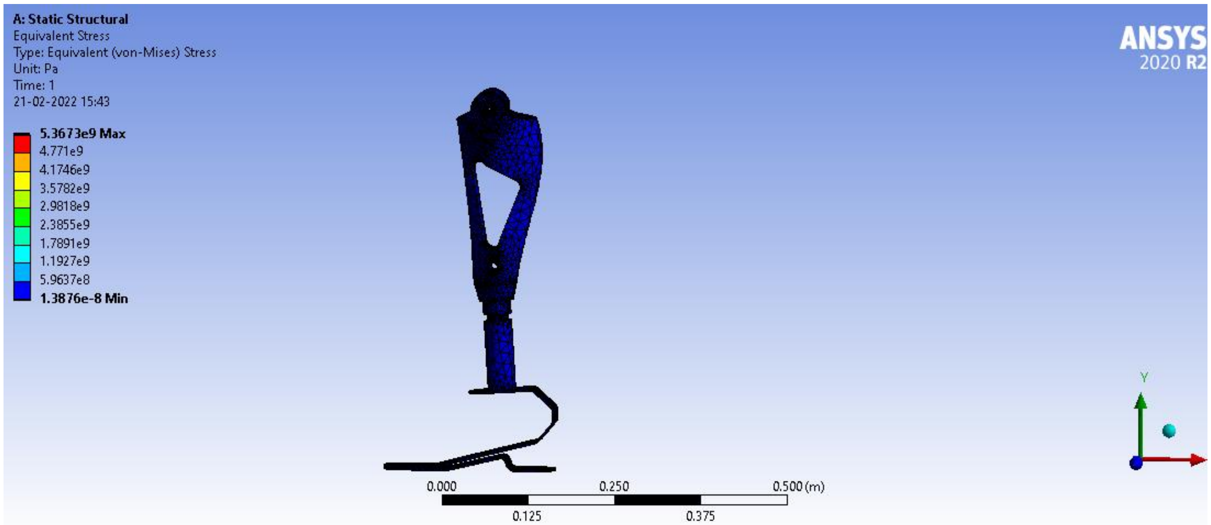
Combination of materials

Combination of materials

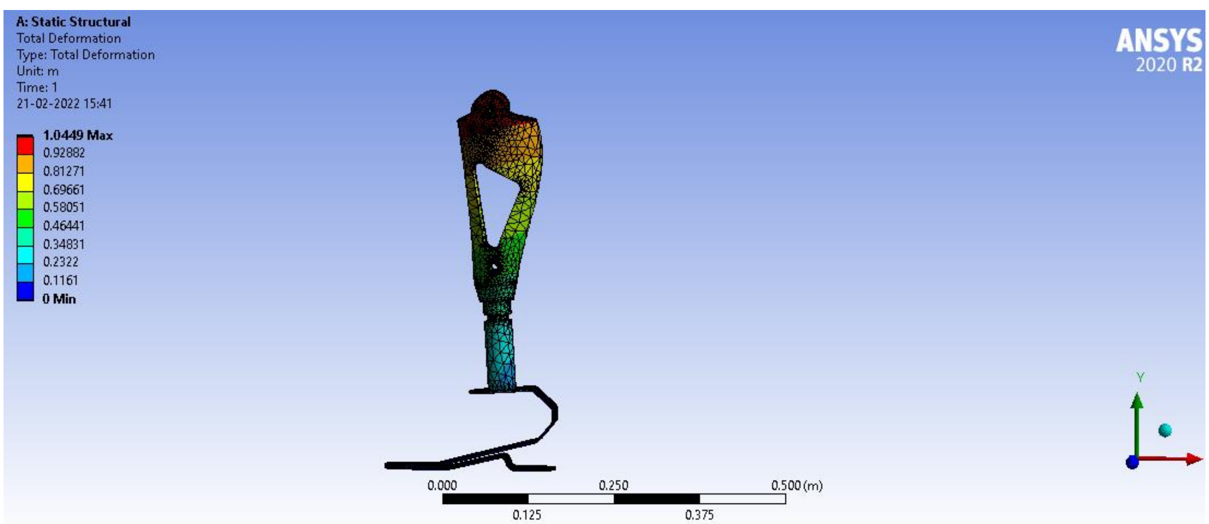
Shaft = Titanium Alloy , base foot = carbon fiber epoxy , thy support = carbon fiber

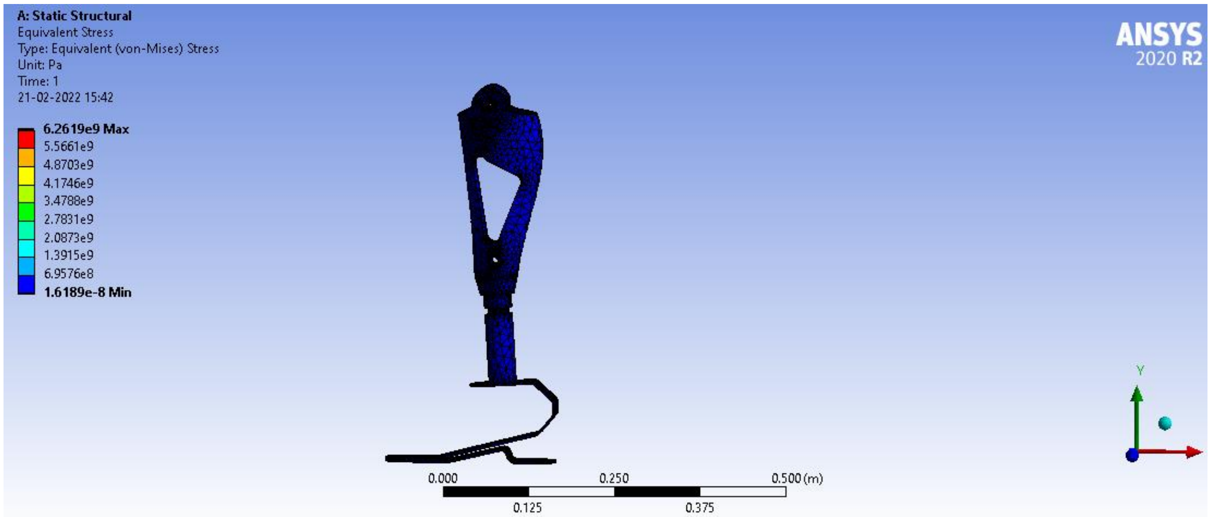
Load = 60 Kg = 588.6N



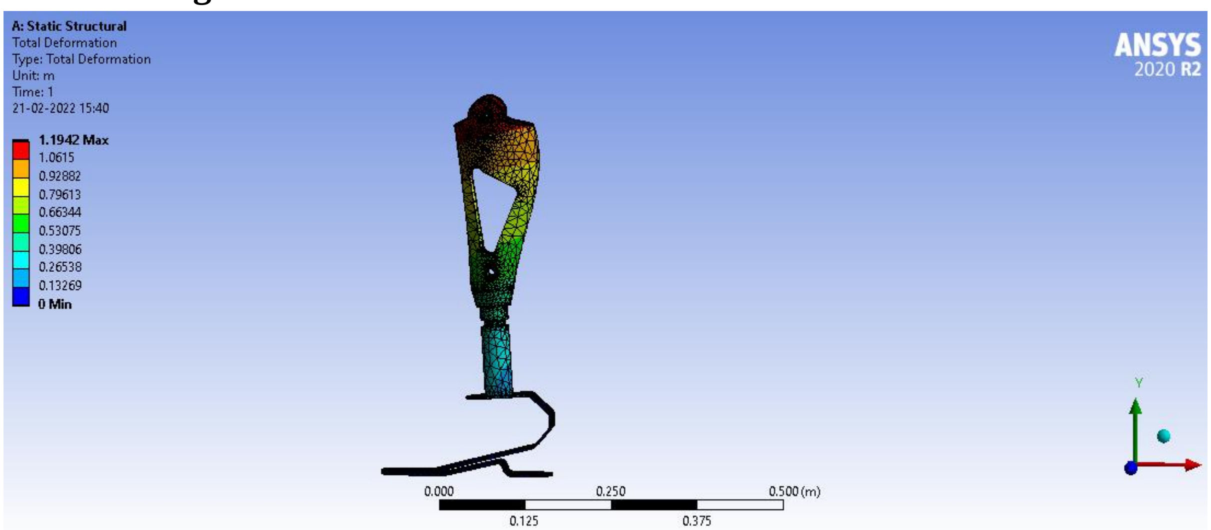


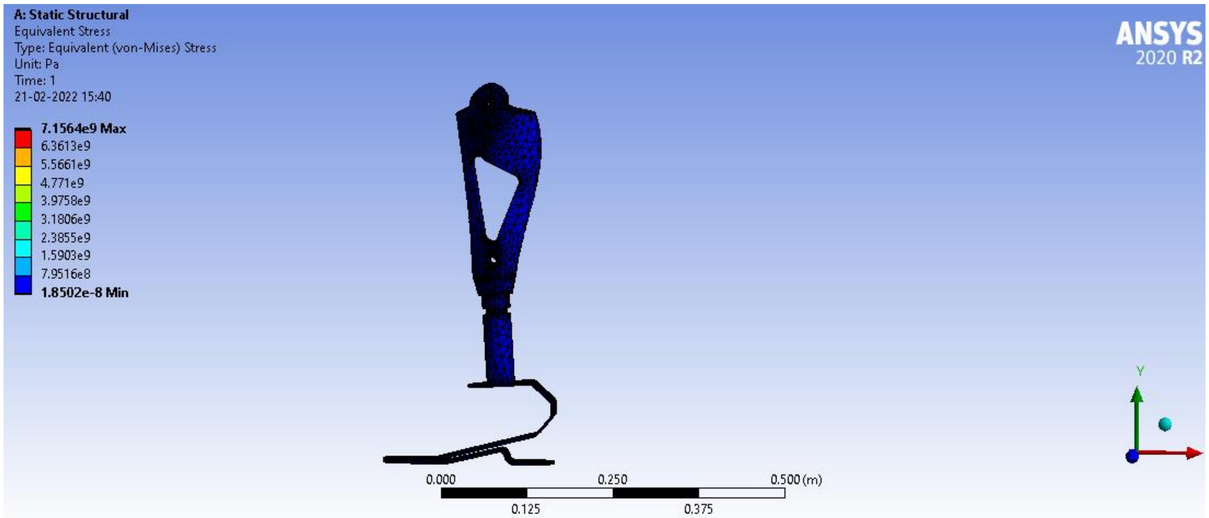
Load = 70 Kg = 686.7N



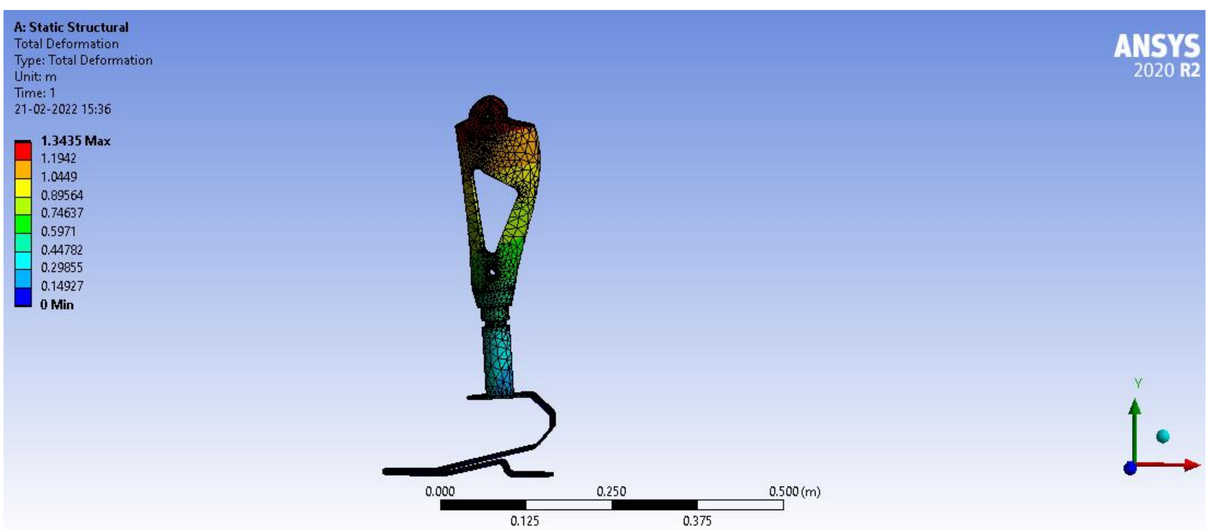


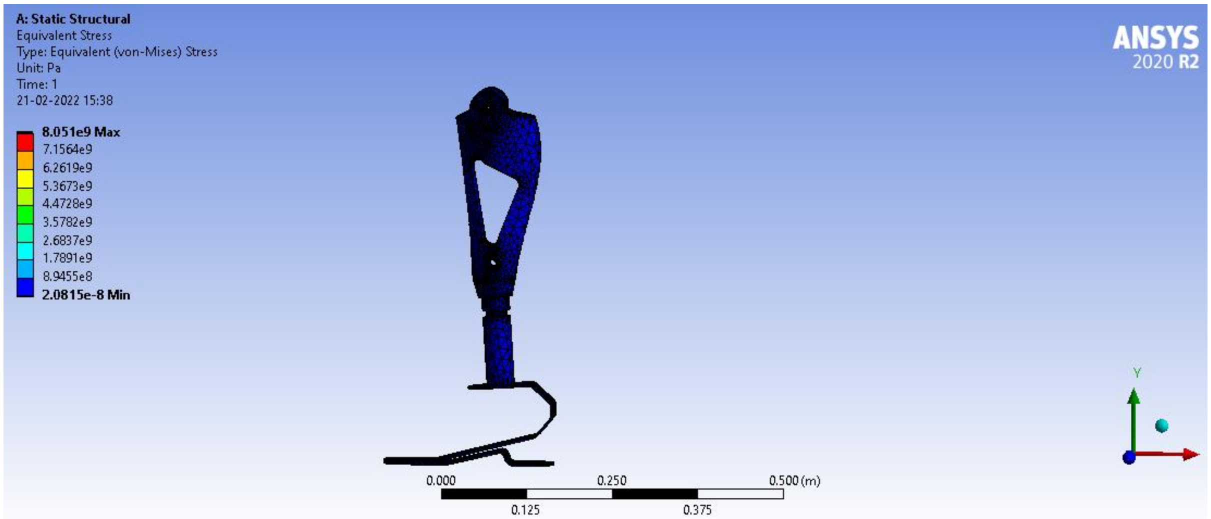
Load =80 Kg = 784.8N



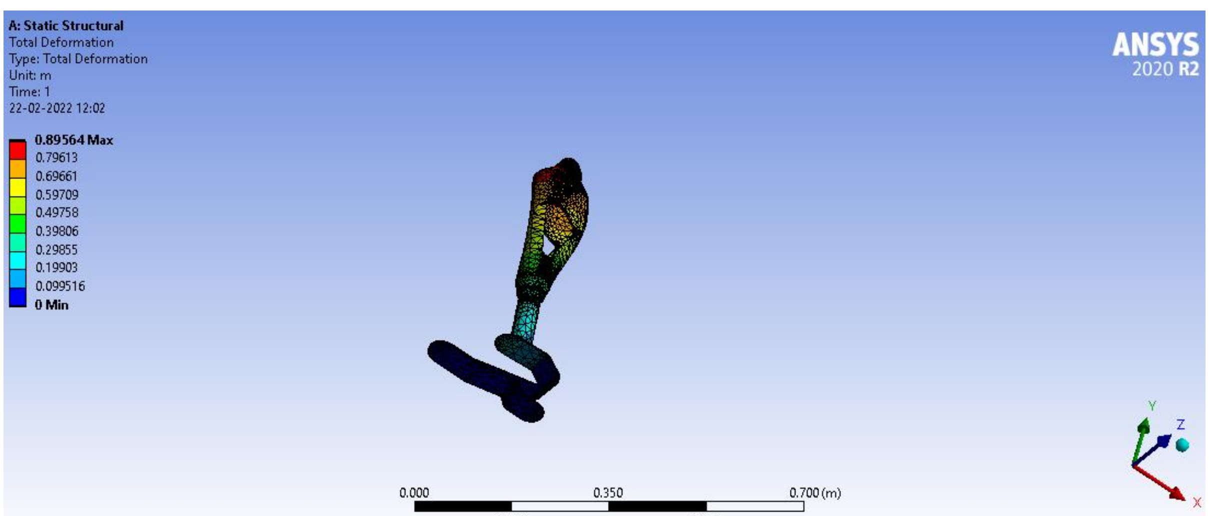


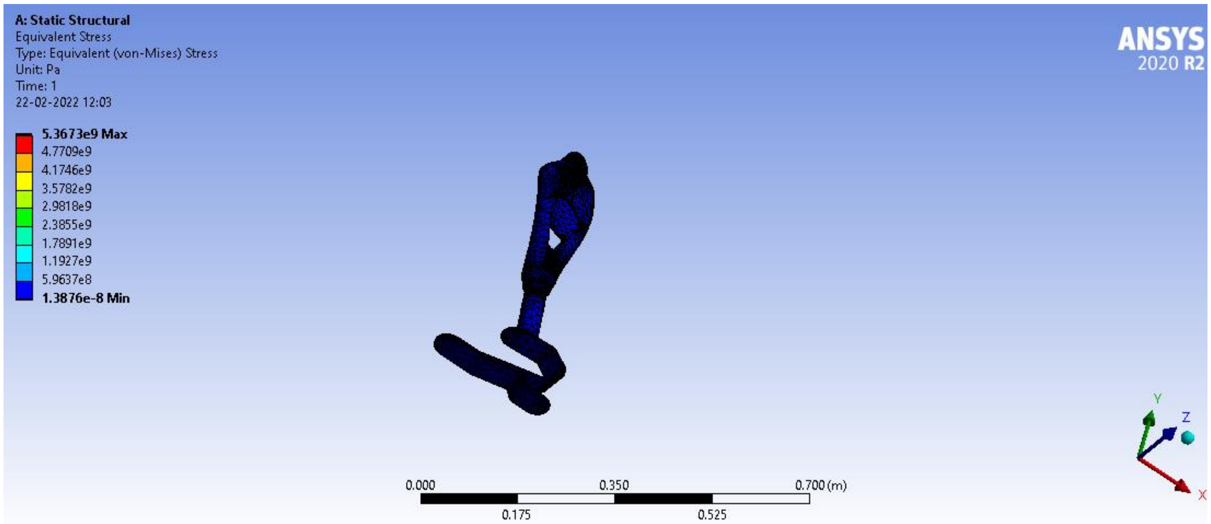
Load 90 Kg = 882.9 N



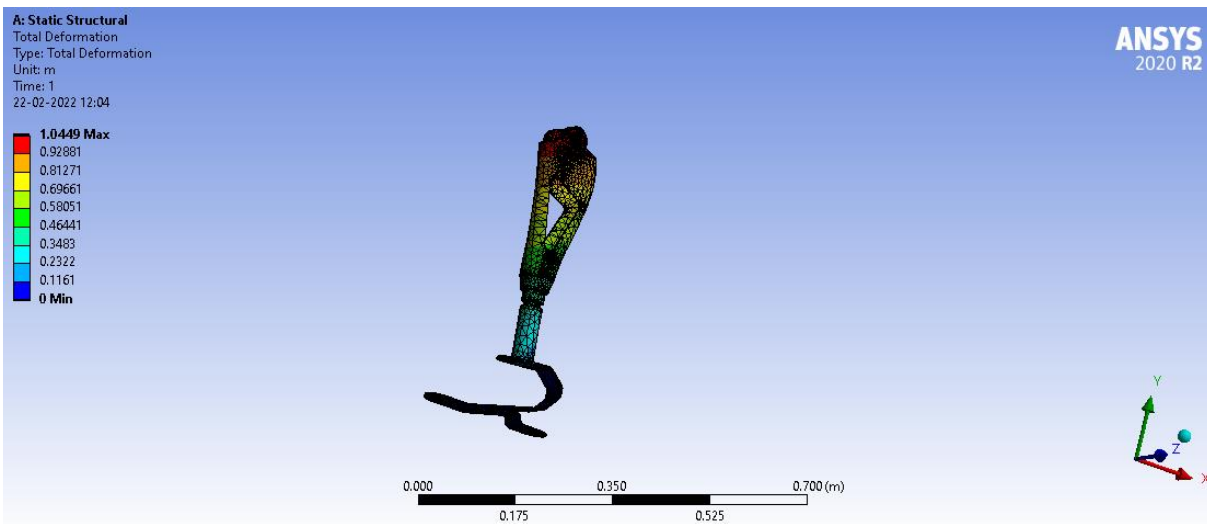


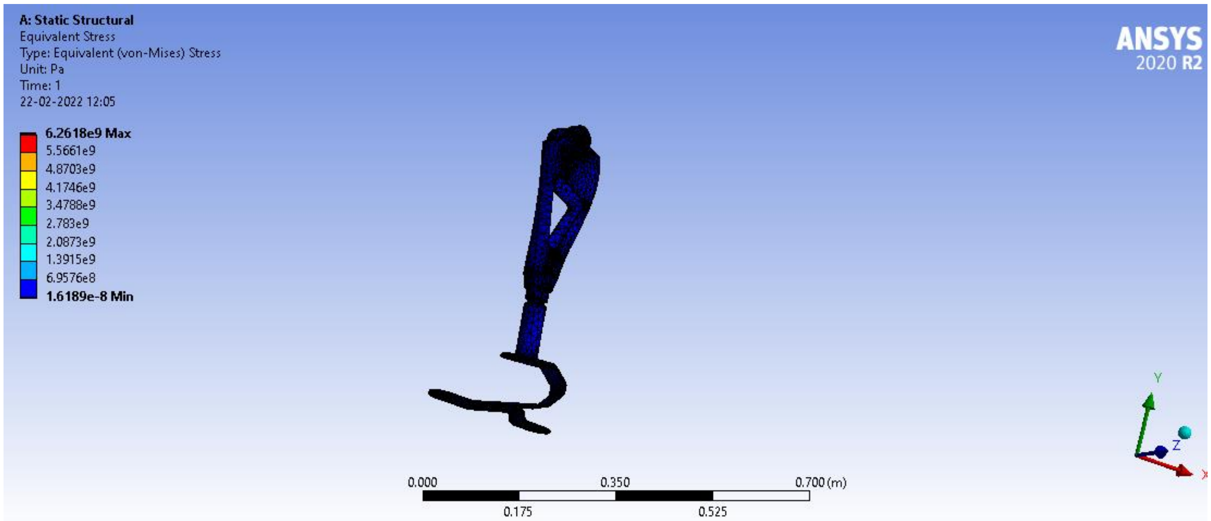
Combination of materials sleeve = Carbon fiber
Shaft = Titanium alloy
Base foot = CF EPOXY
Load =60Kg = 588.6N



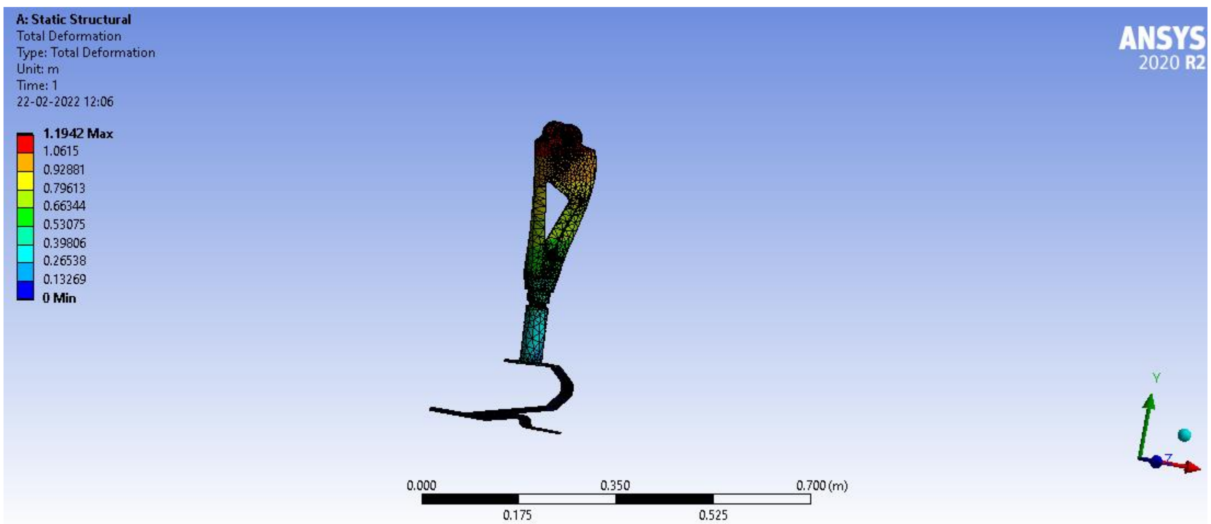


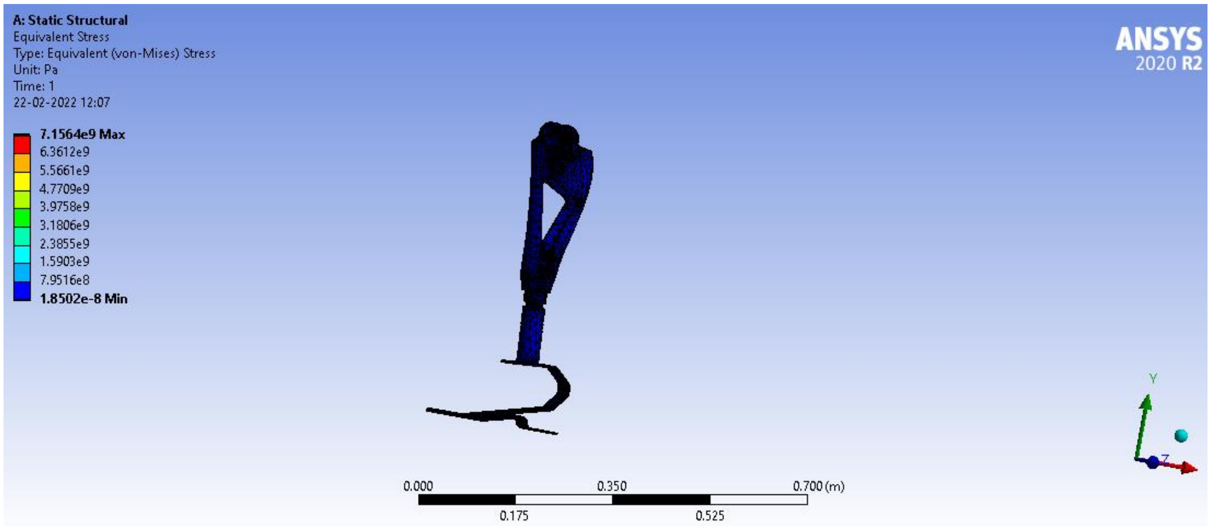
Load 70 kg = 686.7 N



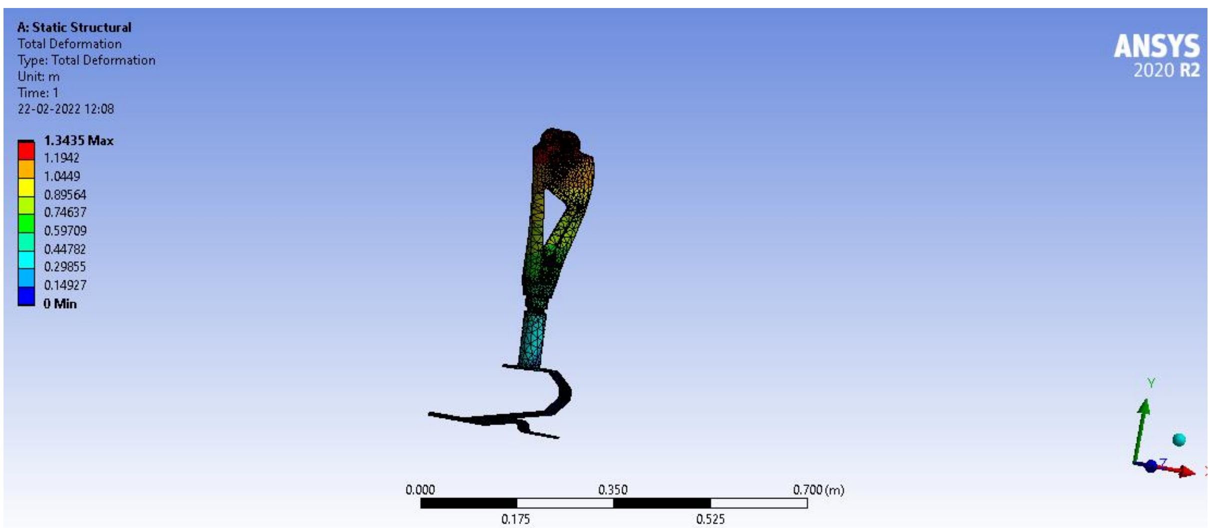


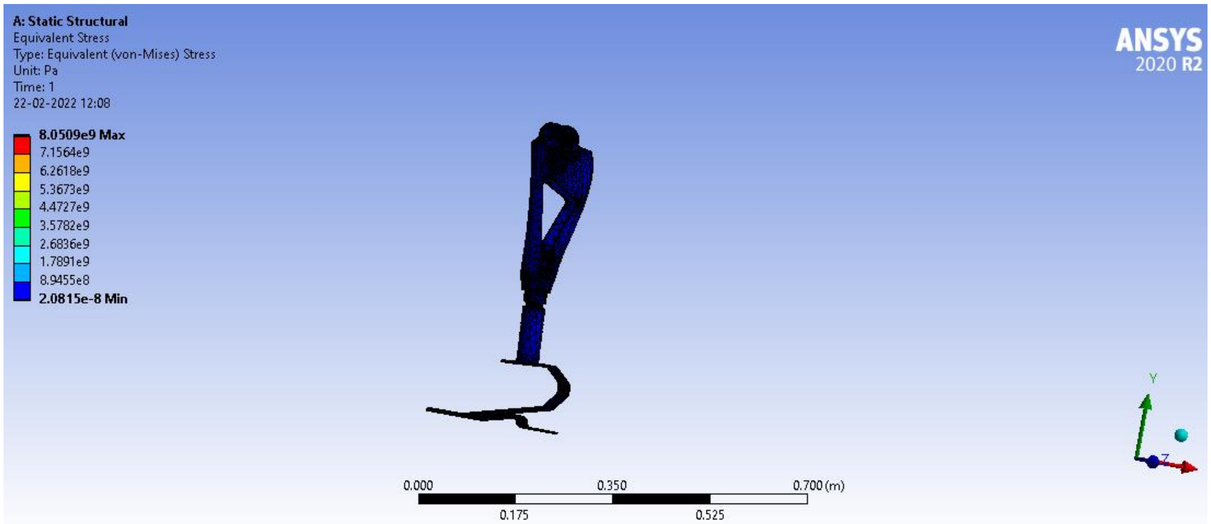
Load =80 Kg =784.8 N



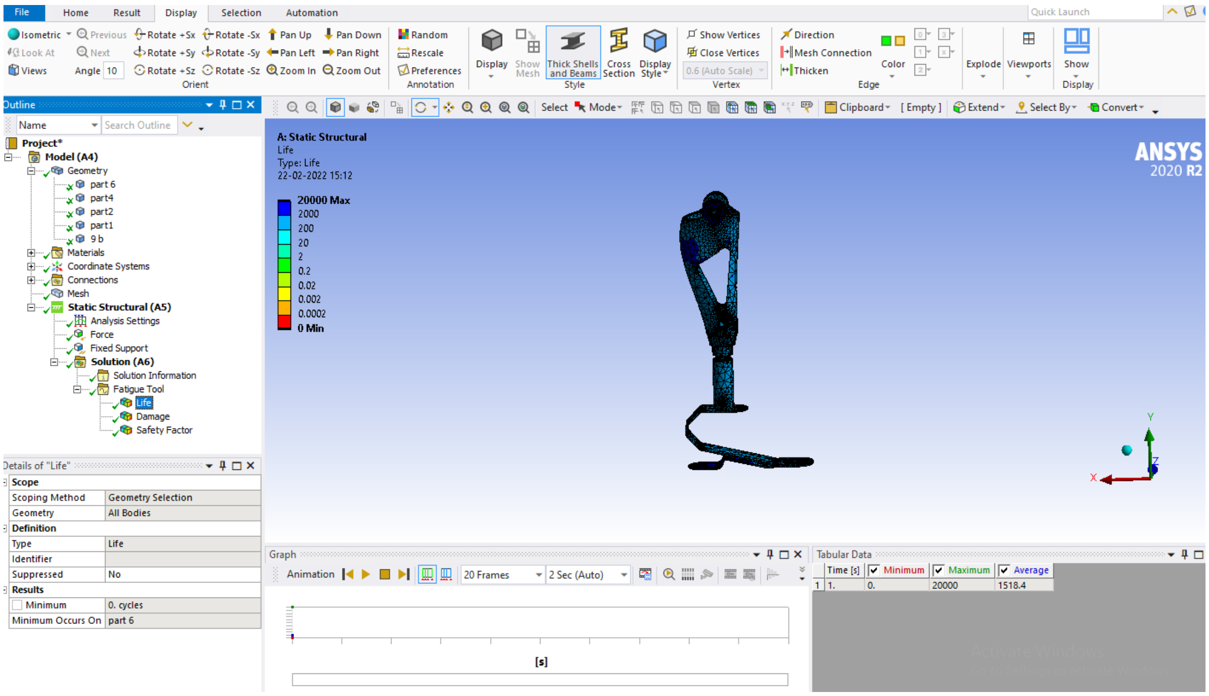


Load= 90 Kg = 882.9N




A: Static Structural
Equivalent Stress
Type: Equivalent (von-Mises) Stress
Unit: Pa
Time: 1
22-02-2022 12:08
8.0509e9 Max
7.1564e9
6.2618e9
5.3673e9
4.4727e9
3.5782e9
2.6836e9
1.7891e9
8.9455e8
2.0815e-8 Min
ANSYS
2020 R2
0.000
0.350
0.700 (m)
0.175
0.525
Y
Z

5. Ansys Workbench Fatigue Module



While many parts may work well initially, they often fail in service due to fatigue failure caused by repeated cyclic loading. Characterizing the capability of a material to survive the many cycles a component may experience during its lifetime is the aim of fatigue analysis. In a general sense, Fatigue Analysis has three main methods, Strain Life, Stress Life, and Fracture Mechanics; the first two being available within the ANSYS Fatigue Module.

Total Life Approaches

- High cycle fatigue (Stress life)
- Low cycle fatigue (Strain life)

1	Cycles	Alternating Stress (MPa)
2	10	3999
3	20	2827
4	50	1896
5	100	1413
6	200	1069
7	1000	500
8	2000	441
9	10000	262
10	20000	214
*		

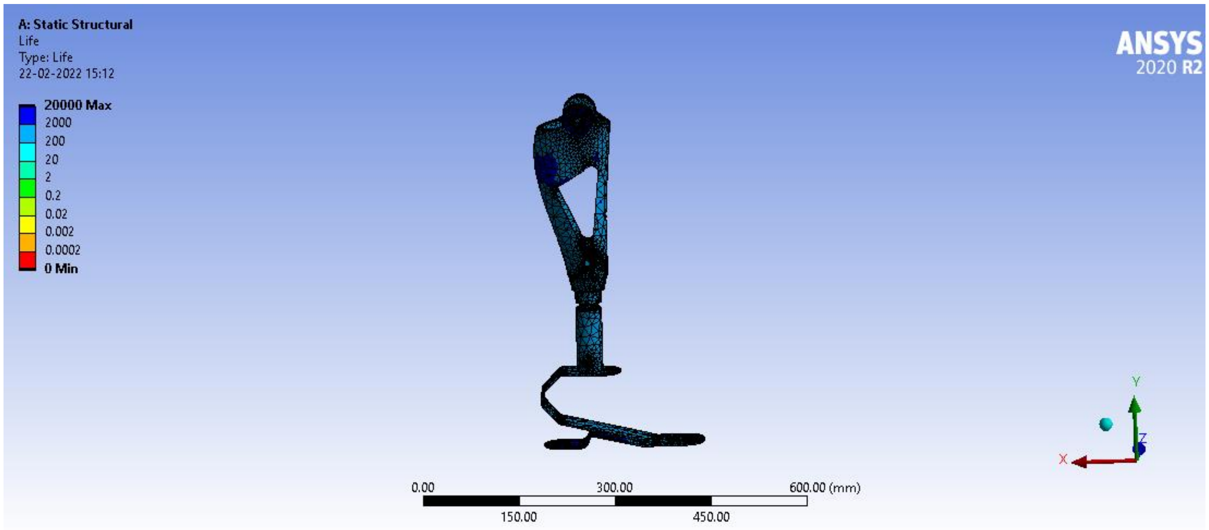
Types of Results

Just like some of the input decisions change depending upon whether you are performing a Stress Life or a Strain Life analysis, calculations and results can be dependent upon the type of fatigue analysis. Results can range from contour plots of a specific result over the whole model to information about the most damaged point in the model (or the most damaged point in the scope of the result). Results that are common to both types of fatigue analyses are listed below:

- Fatigue life
- Fatigue damage at a specified design life
- Fatigue factor of safety at a specified design life

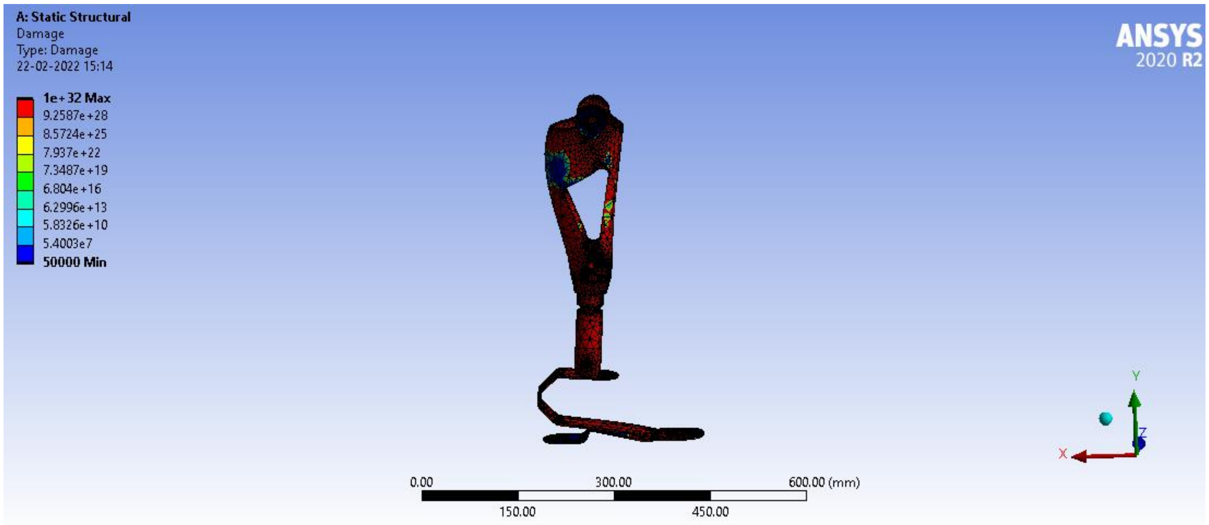
General Fatigue Results

1-Fatigue Life



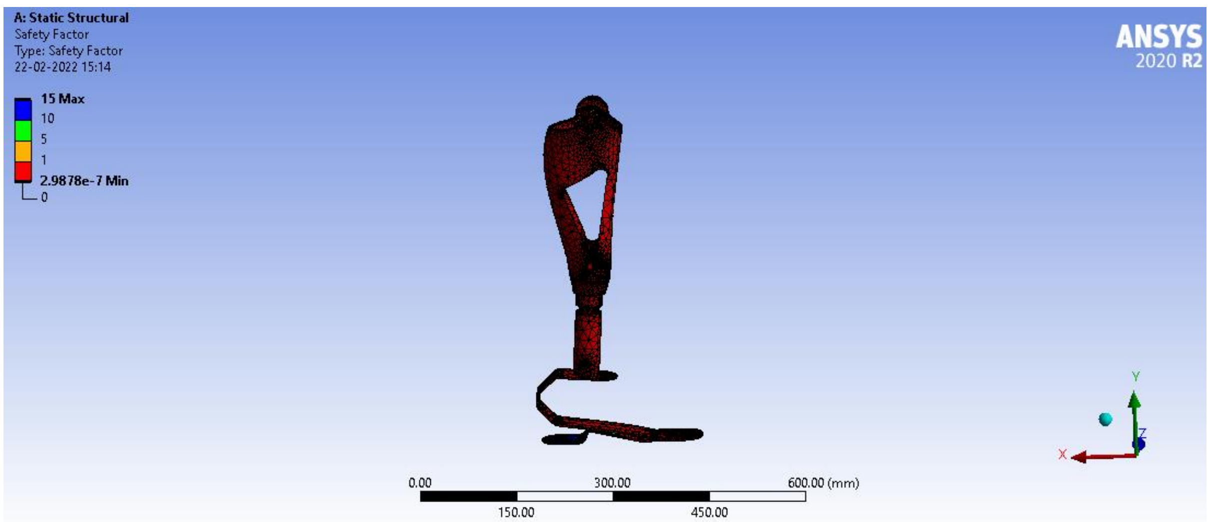
. Fatigue Life can be over the whole model or scoped just like any other contour result in Workbench (i.e. parts, surfaces, edges, and vertices). In addition, this and any contour result may be exported to a tab-delimited text file by a right mouse button click on the result. This result contour plot shows the available life for the given fatigue analysis. If loading is of constant amplitude, this represents the number of cycles until the part will fail due to fatigue. If loading is non-constant, this represents the number of loading blocks until failure

2- Fatigue Damage



Fatigue Damage is a contour plot of the fatigue damage at a given design life. Fatigue damage is defined as the design life divided by the available life. This result may be scoped. The default design life may be set through the Control Panel. For Fatigue Damage, values greater than 1 indicate failure before the design life is reached.

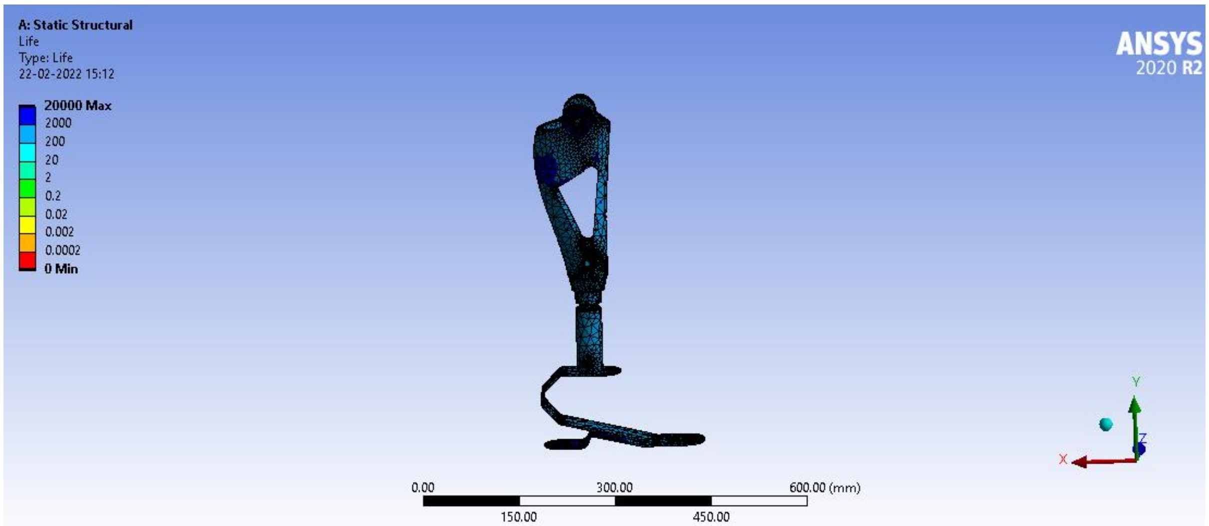
3- Fatigue Safety Factor

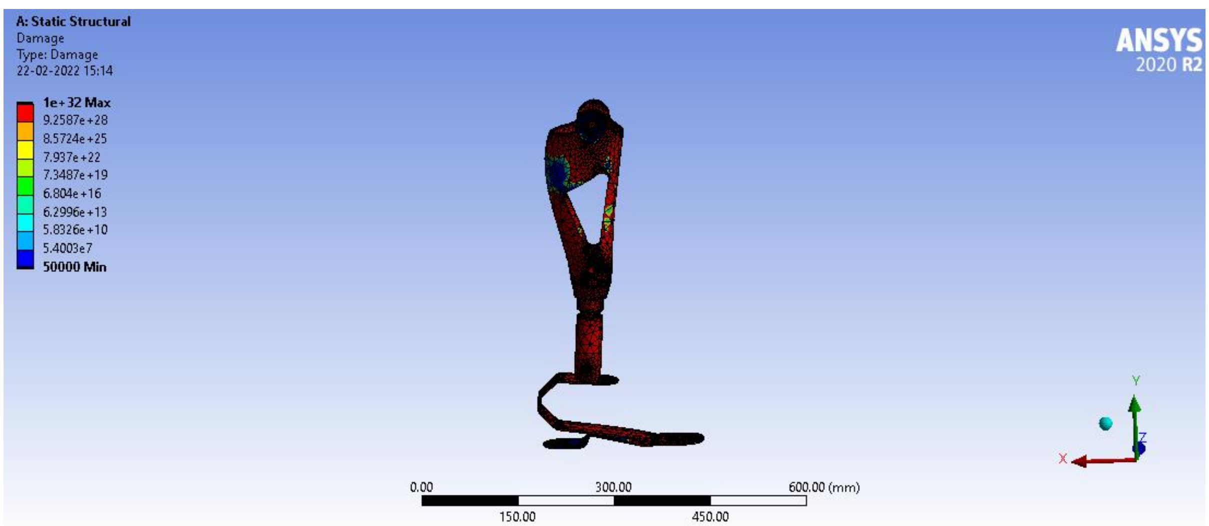


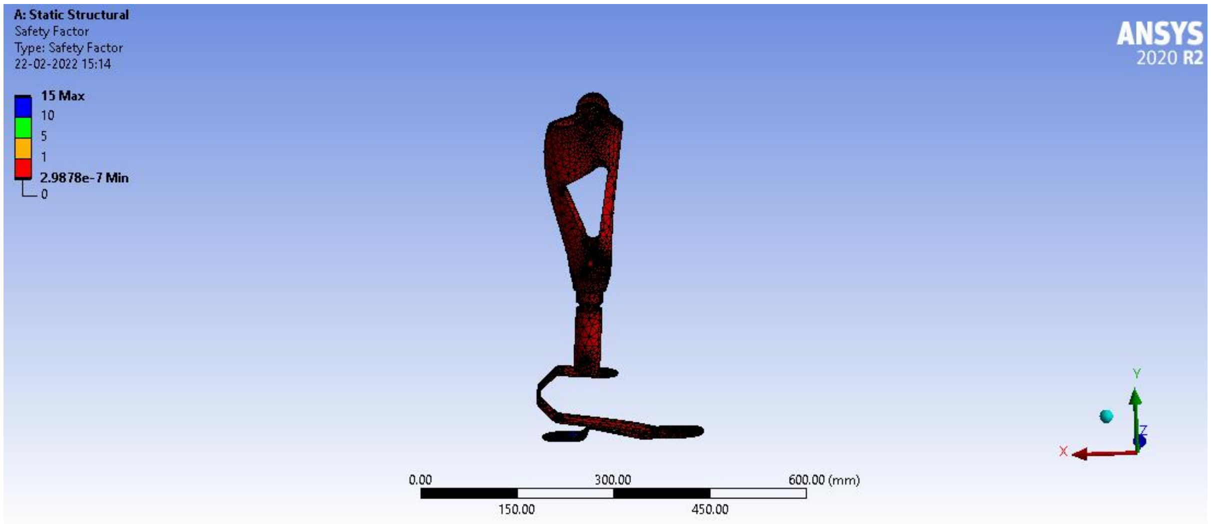
Fatigue Safety Factor is a contour plot of the factor of safety with respect to a fatigue failure at a given design life. The maximum Factor of Safety displayed is

15. Like damage and life, this result may be scoped. For Fatigue Safety Factor, values less than one indicate failure before the design life is reached.

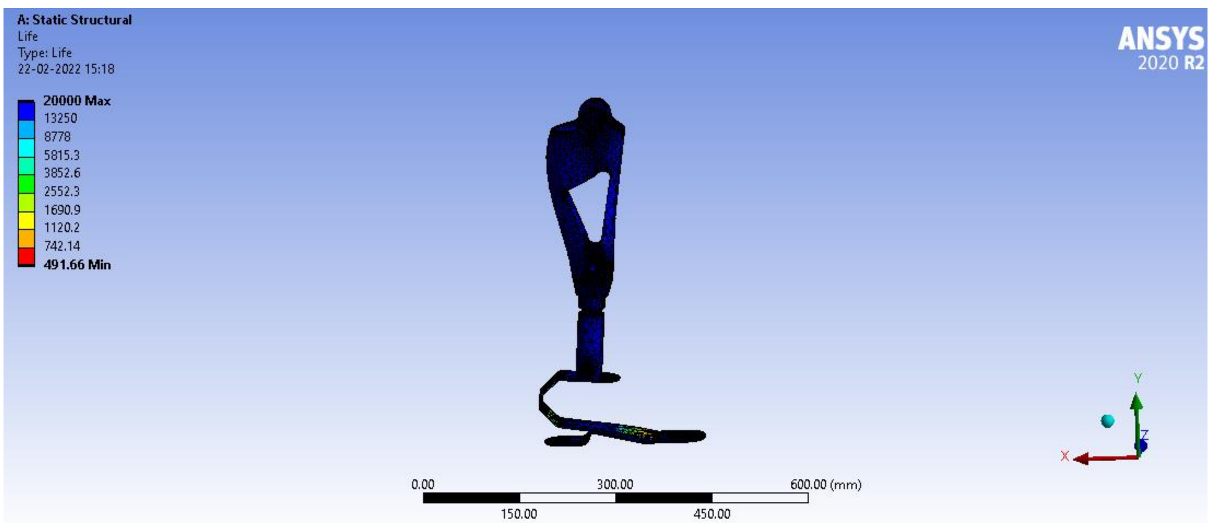
a) Al Alloy 60 Kg

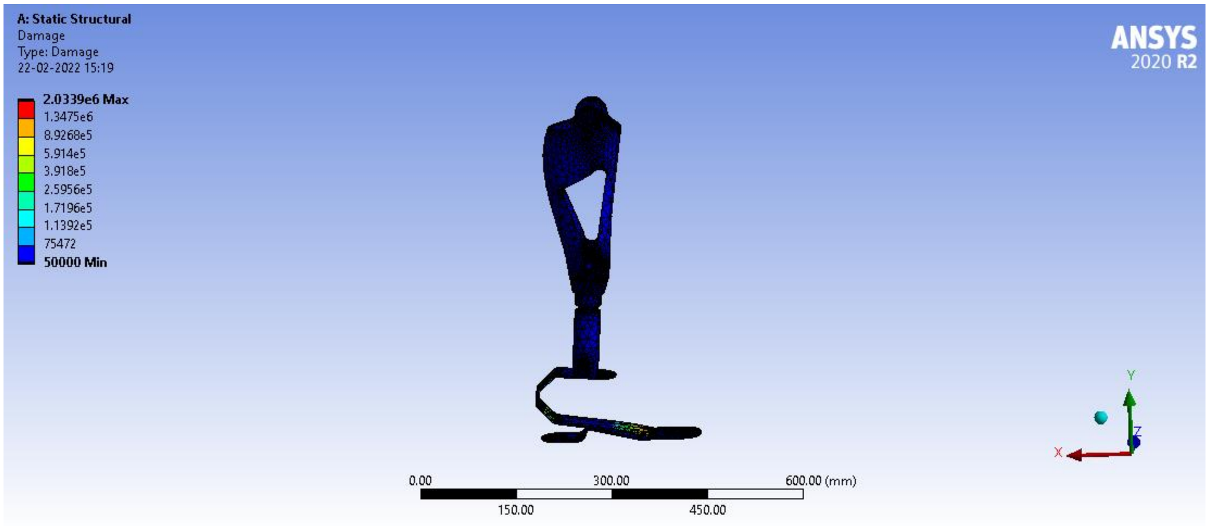




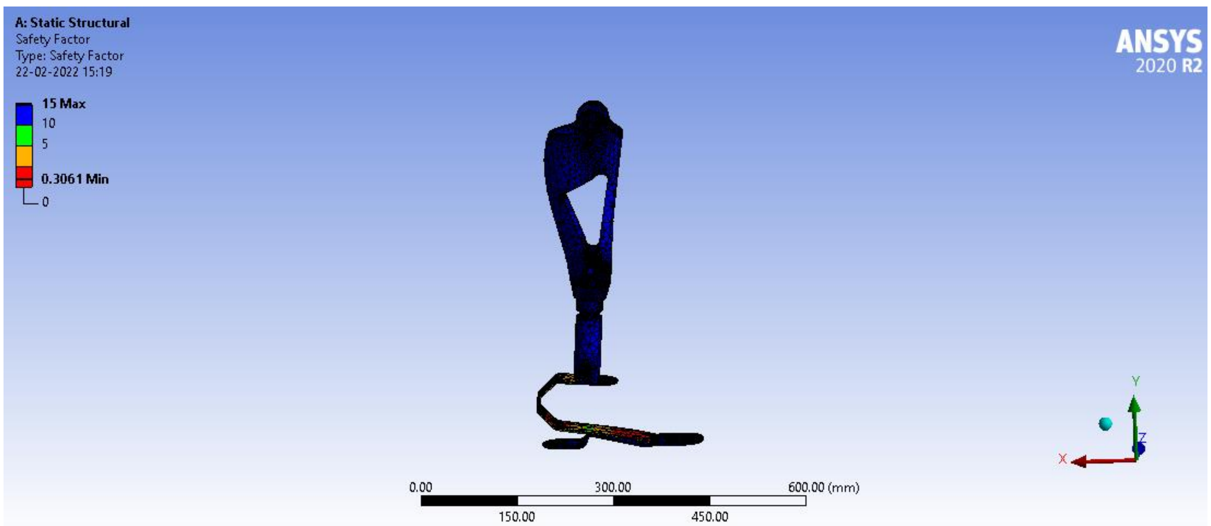


b) Titanium Alloy 60 Kg



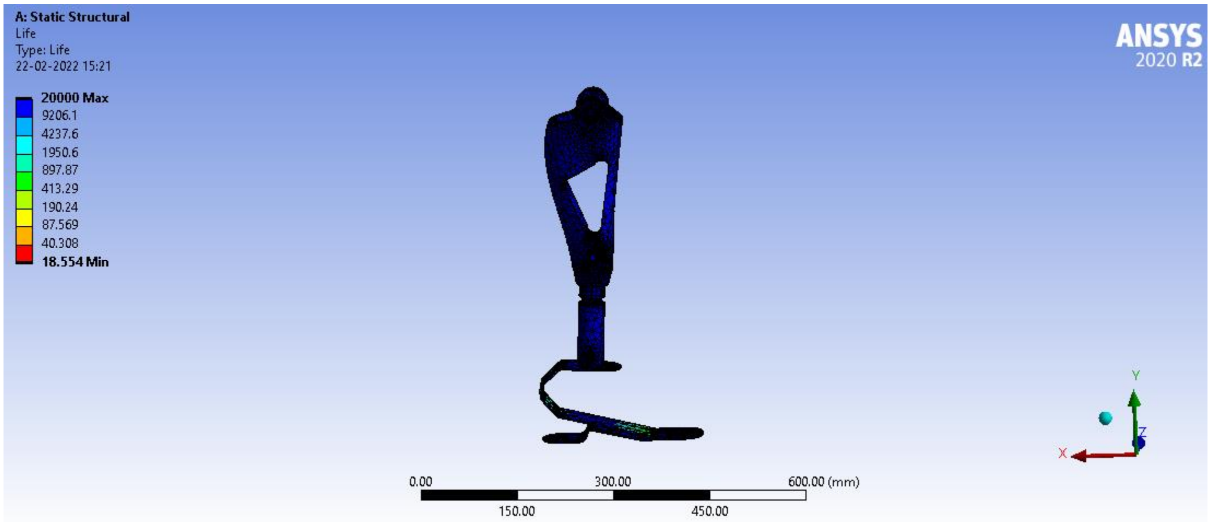


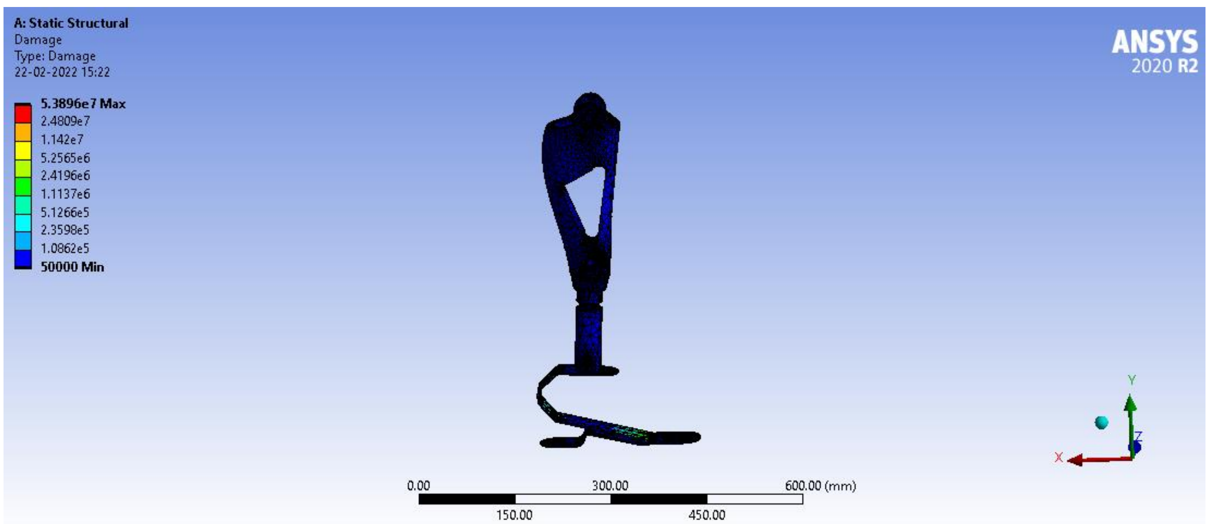
A: Static Structural
Damage
Type: Damage
22-02-2022 15:19
2.0339e6 Max
1.3475e6
8.9268e5
5.914e5
3.918e5
2.5956e5
1.7196e5
1.1392e5
75472
50000 Min
ANSYS
2020 R2
0.00
300.00
600.00 (mm)
150.00
450.00

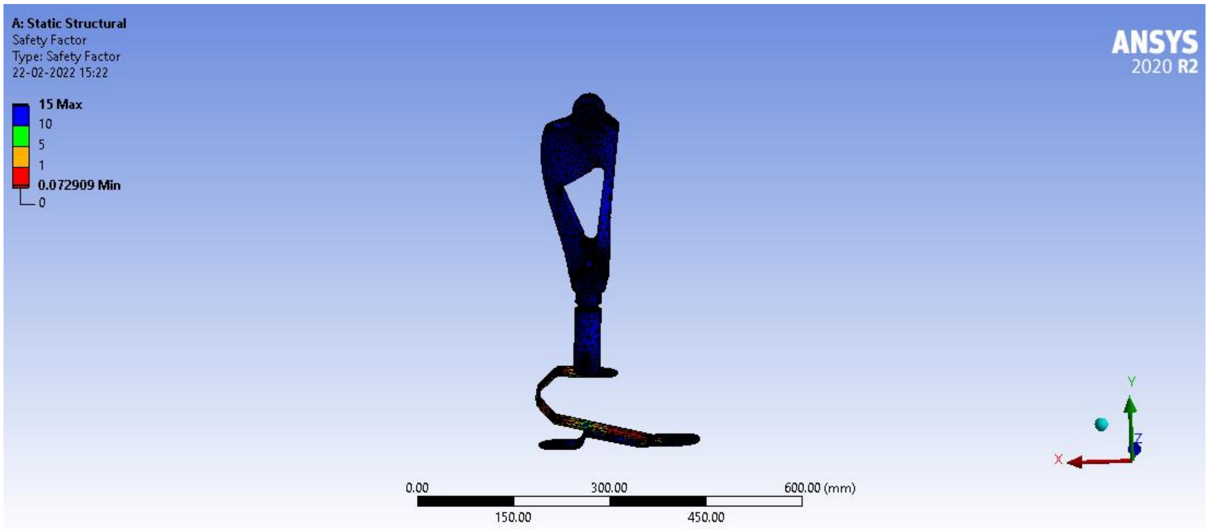


A: Static Structural
Safety Factor
Type: Safety Factor
22-02-2022 15:19
15 Max
10
5
0.3061 Min
0
ANSYS
2020 R2
0.00
300.00
600.00 (mm)
150.00
450.00

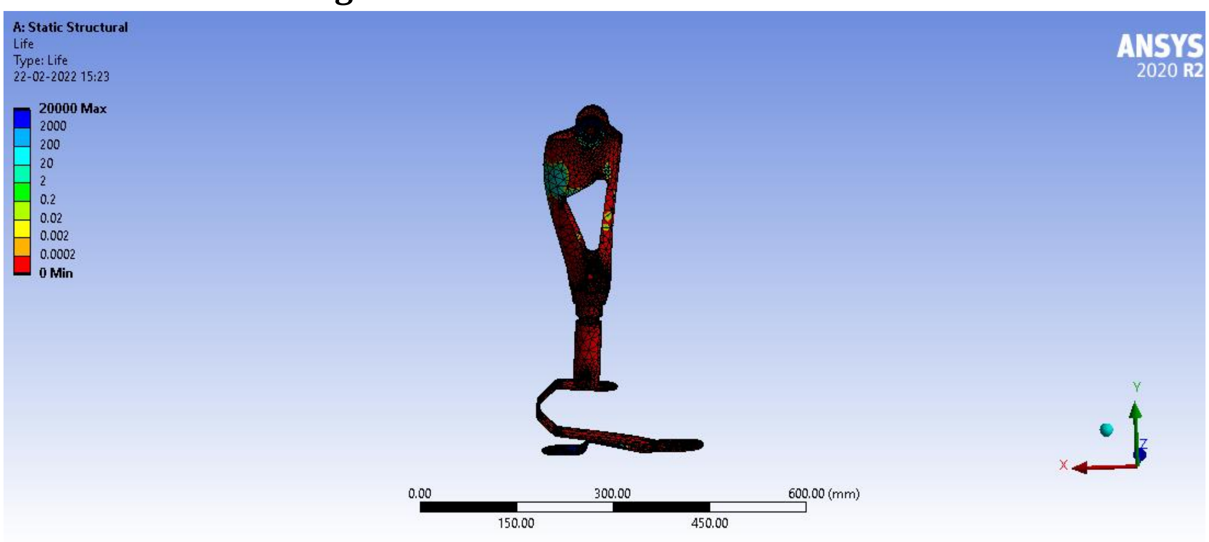
c) Epoxy Carbon UD 395   60 Kg

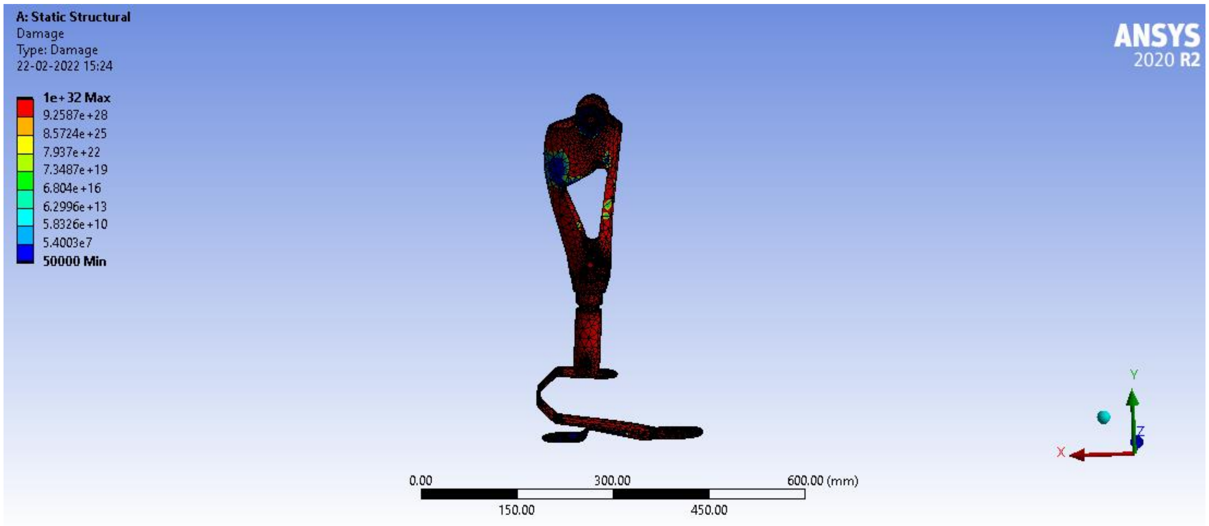


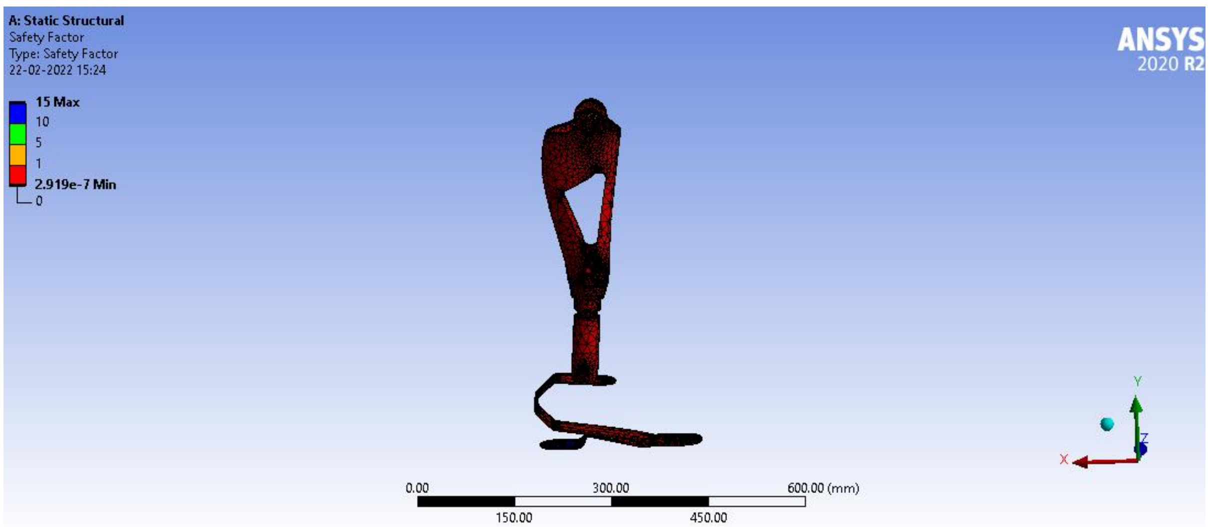




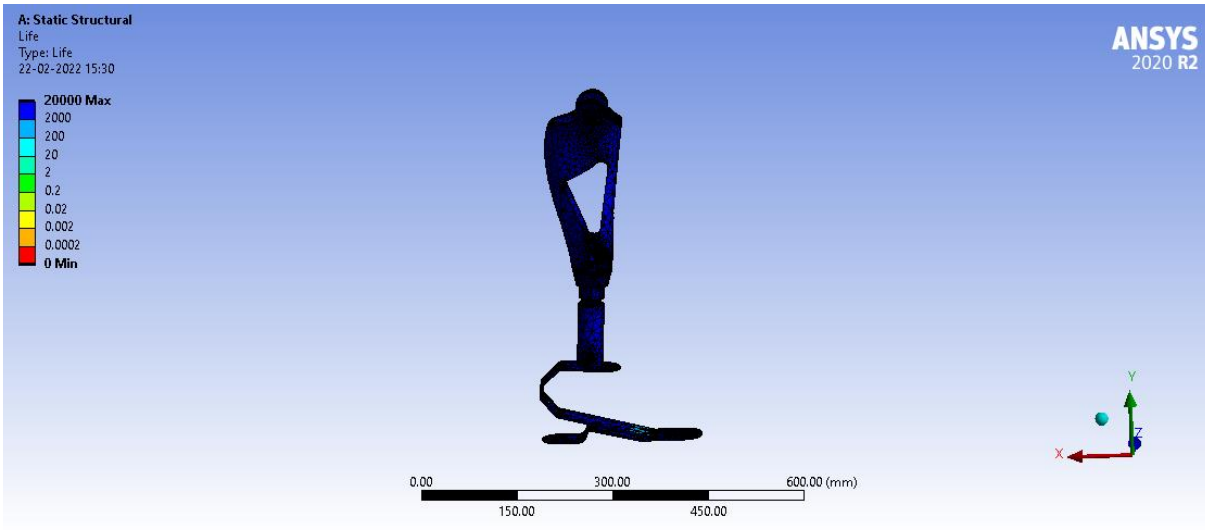
d) Structural steel 60Kg

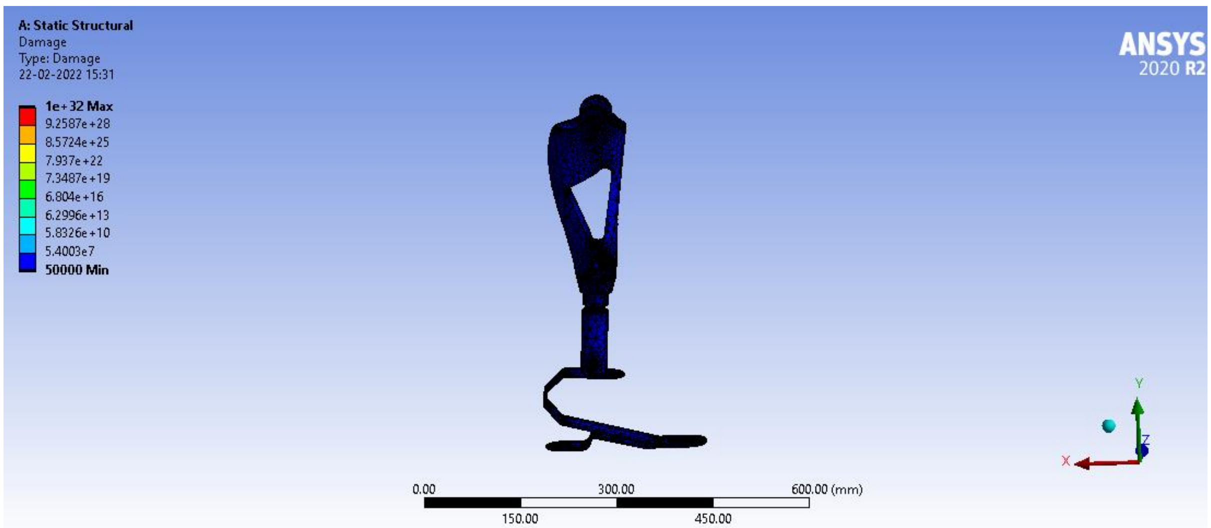


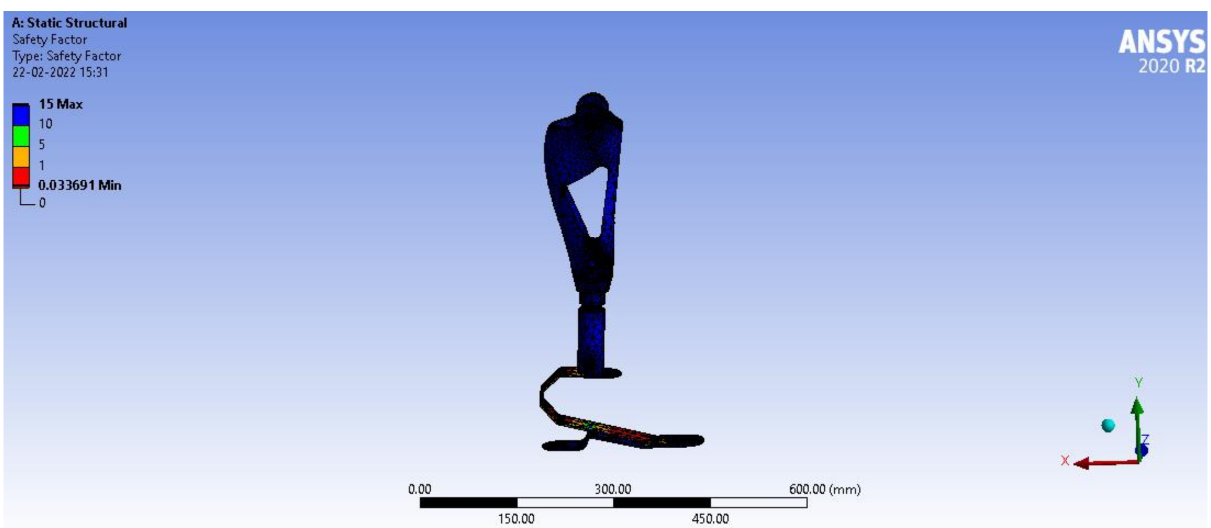

A: Static Structural
Damage
Type: Damage
22-02-2022 15:24
1e+32 Max
9.2587e+28
8.5724e+25
7.937e+22
7.3487e+19
6.804e+16
6.2996e+13
5.8326e+10
5.4003e7
50000 Min
ANSYS
2020 R2
0.00
300.00
600.00 (mm)
150.00
450.00


A: Static Structural
Safety Factor
Type: Safety Factor
22-02-2022 15:24
15 Max
10
5
1
2.919e-7 Min
0
ANSYS
2020 R2
0.00
300.00
600.00 (mm)
150.00
450.00

e) Carbon fiber 395 GPa

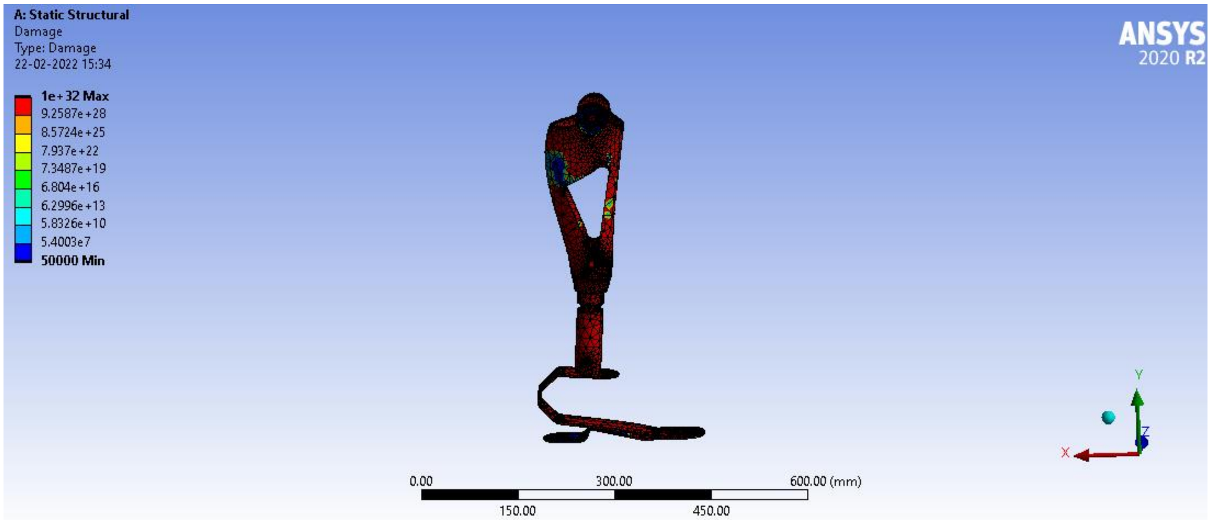


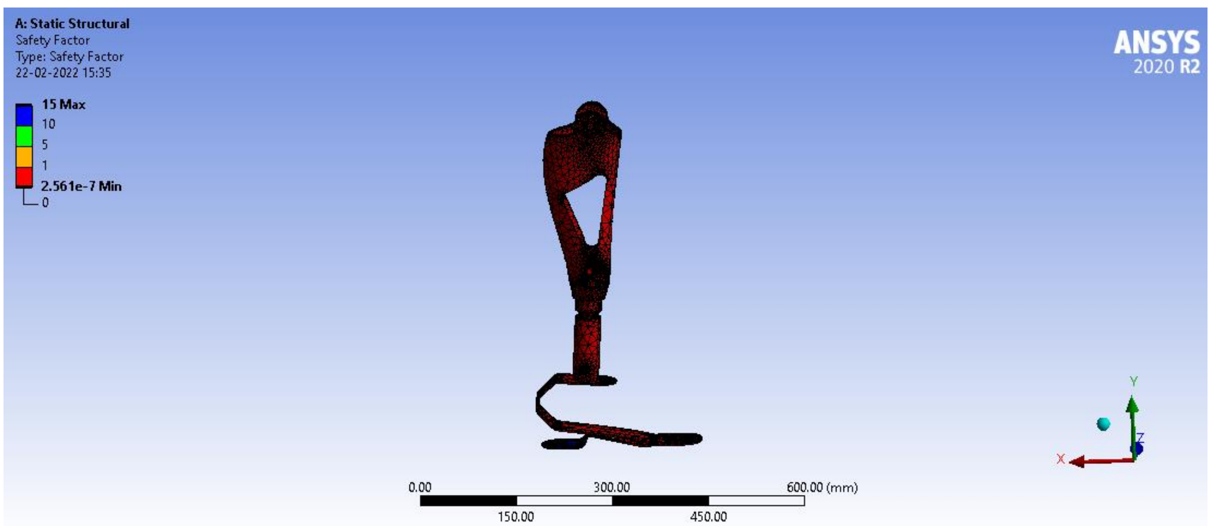




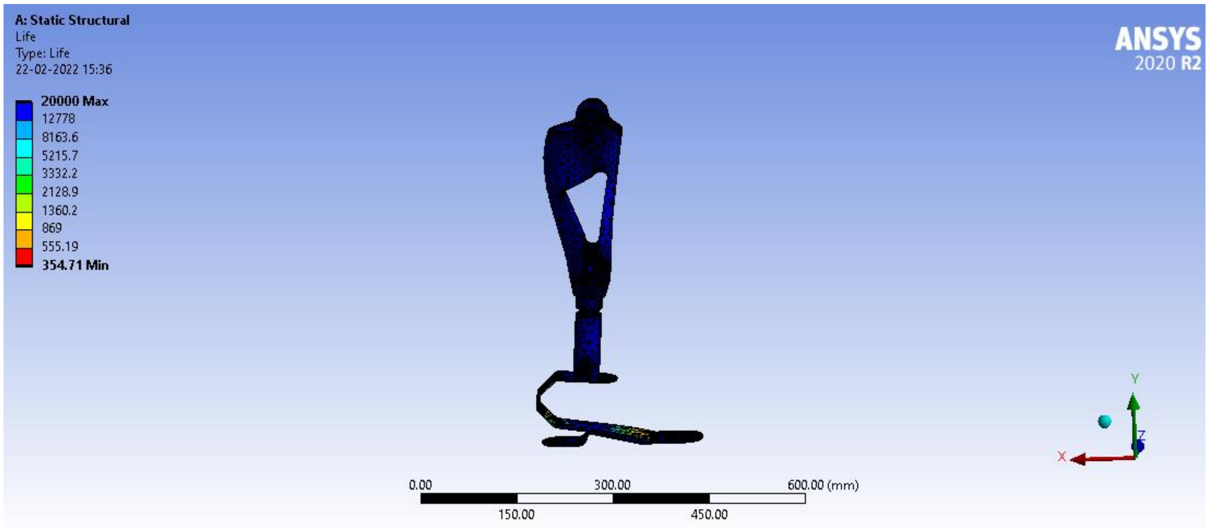
Load 70 Kg= 686.7

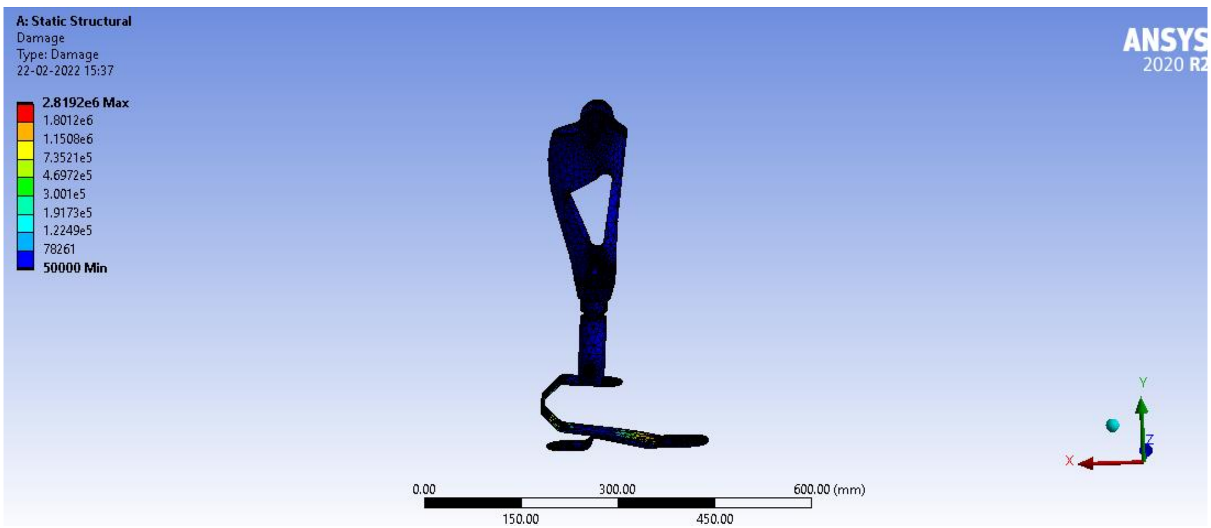
a) Al Alloy

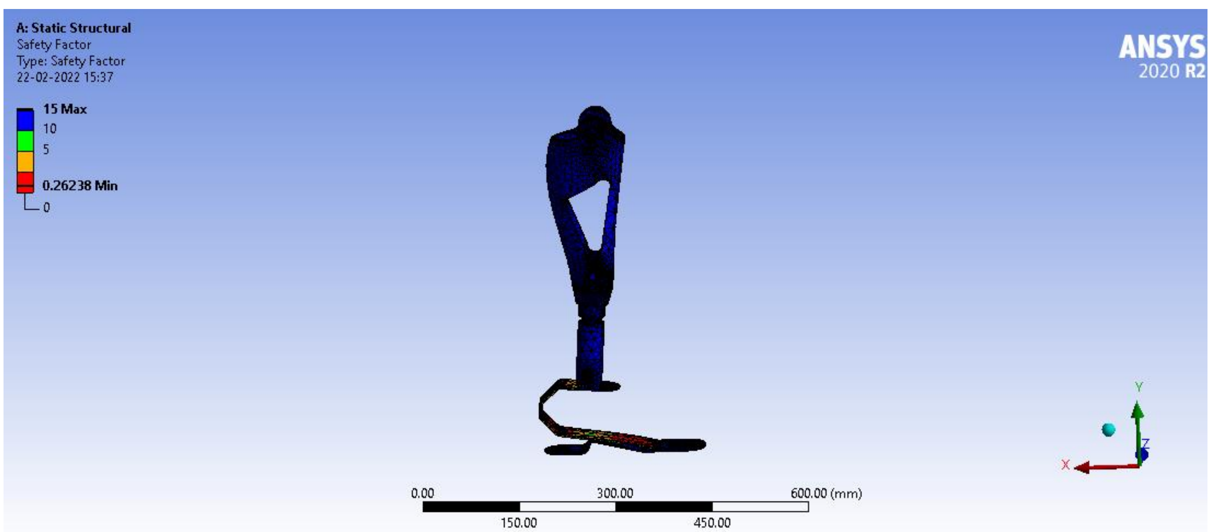




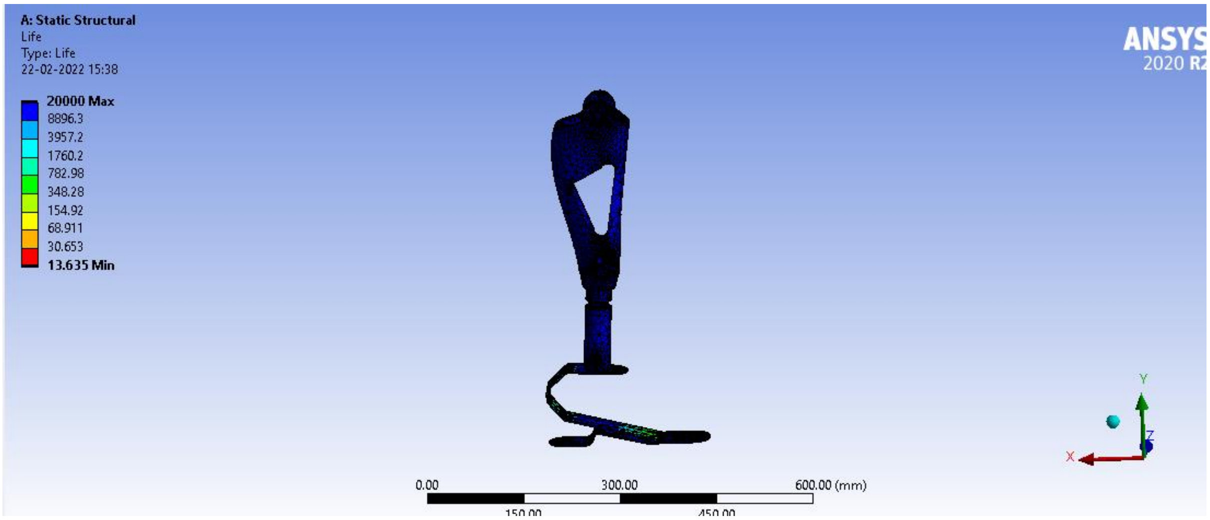
b) Titanium alloy

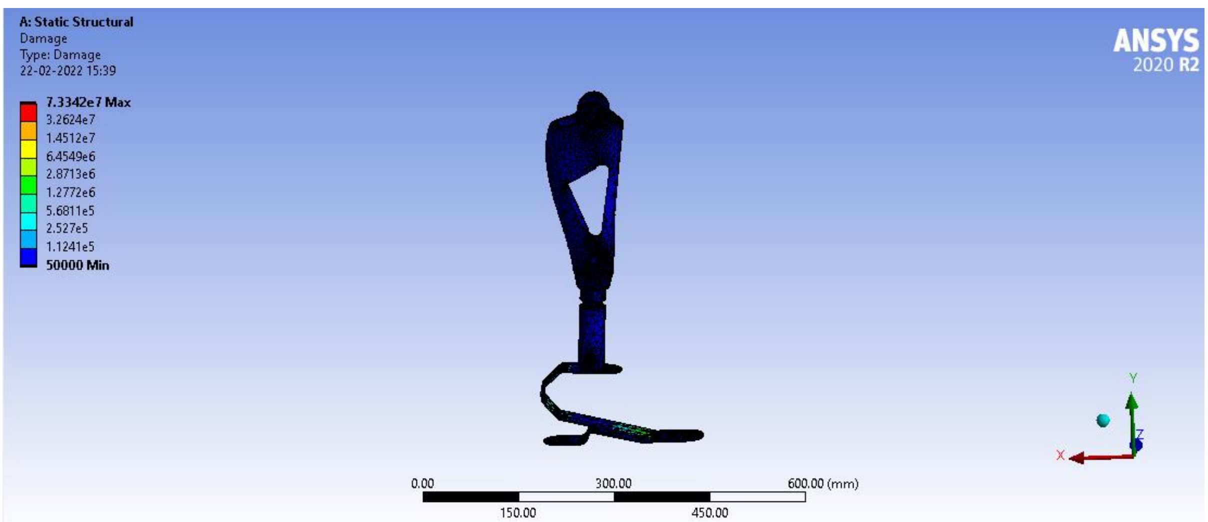


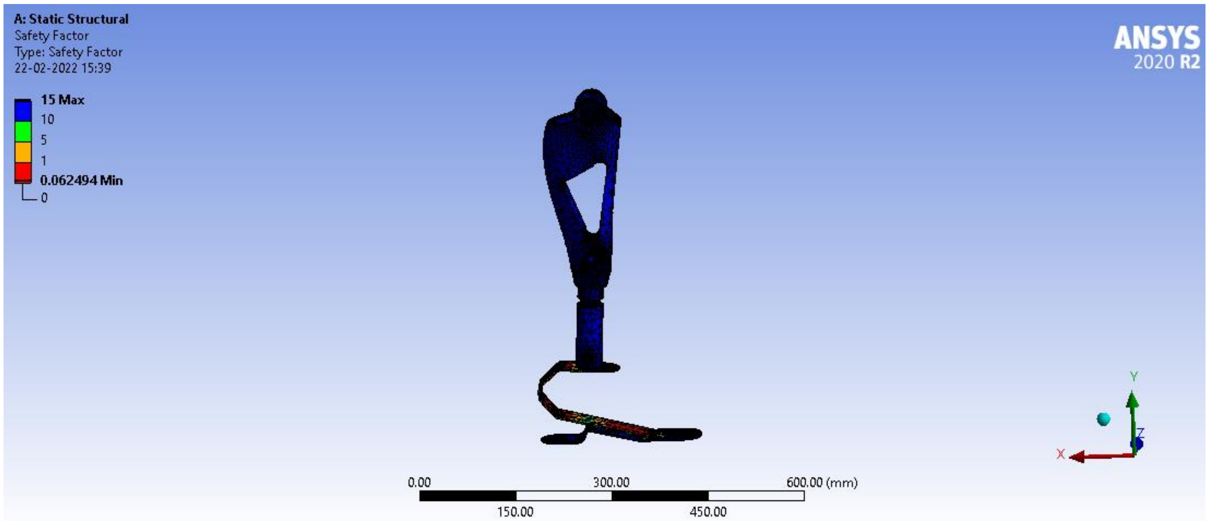




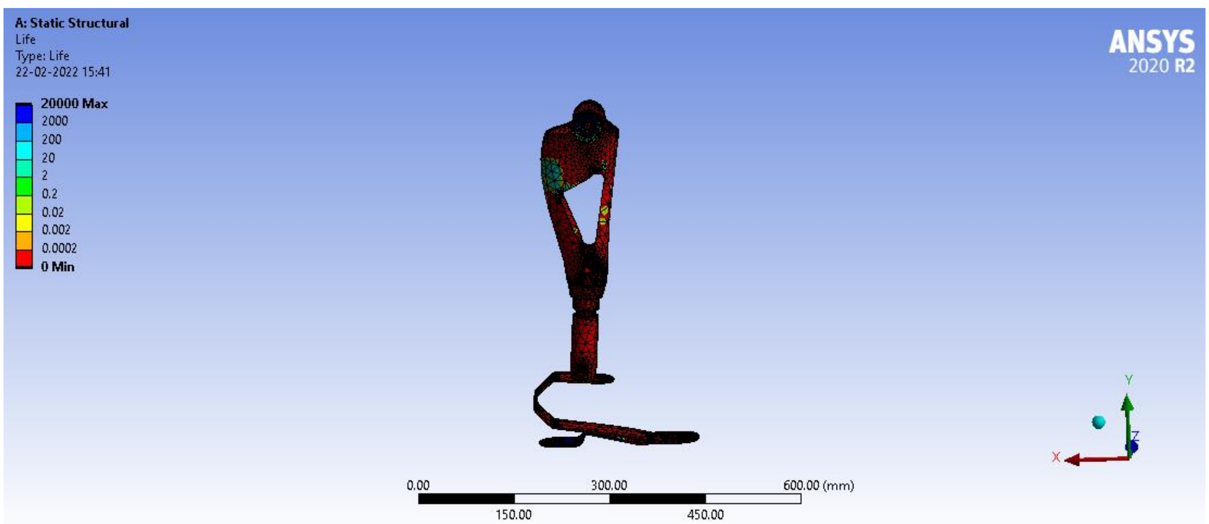
c) carbon fiber epoxy ud

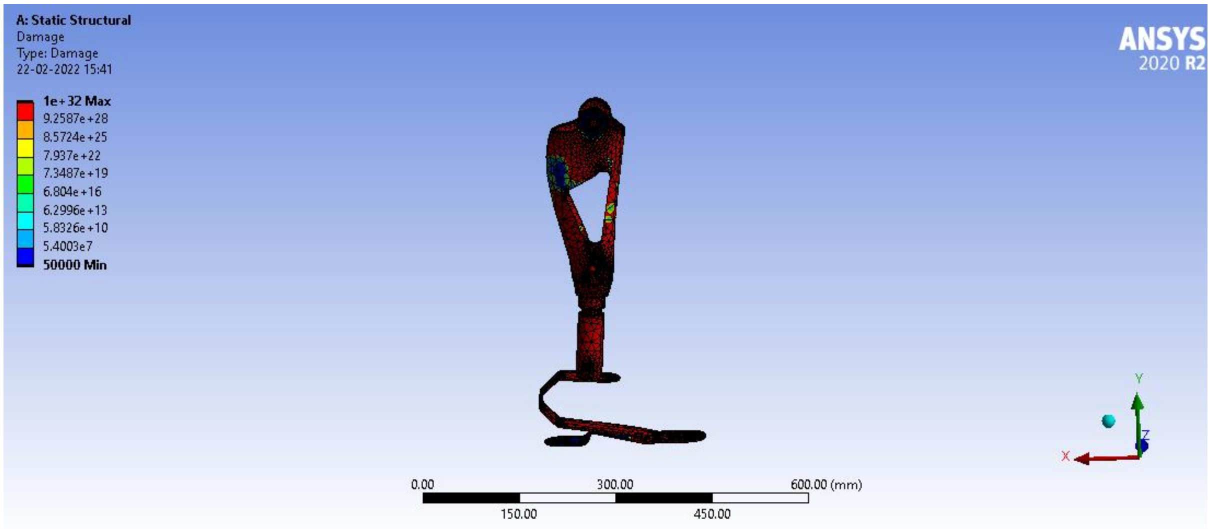


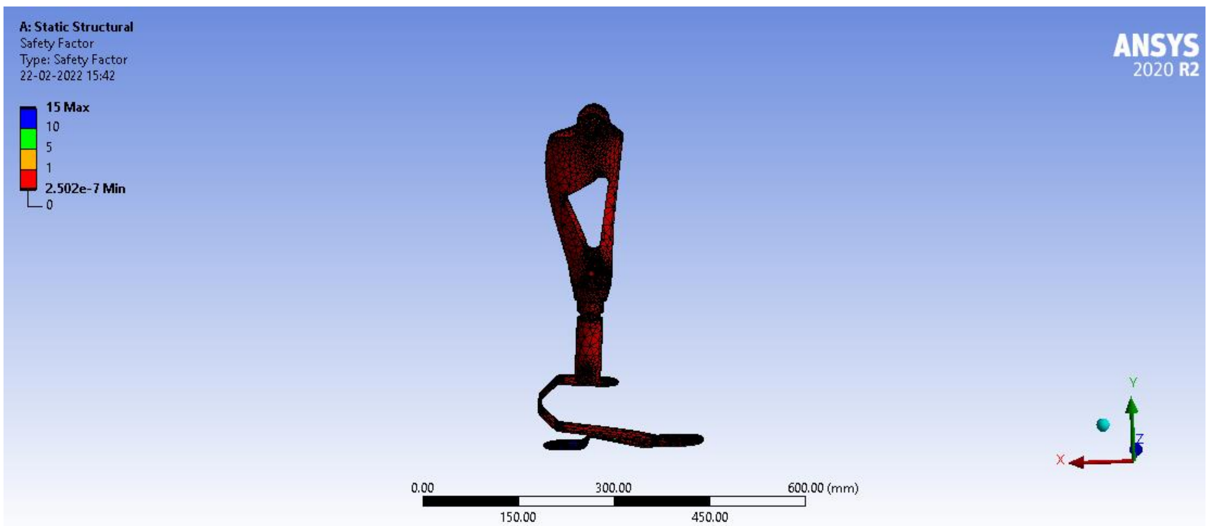




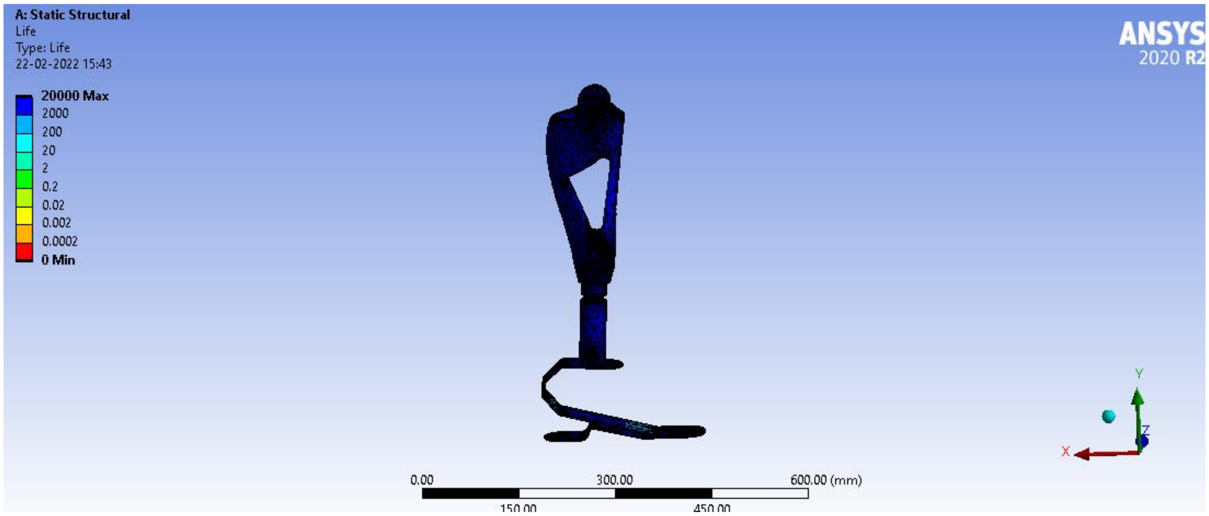
d) structural steel

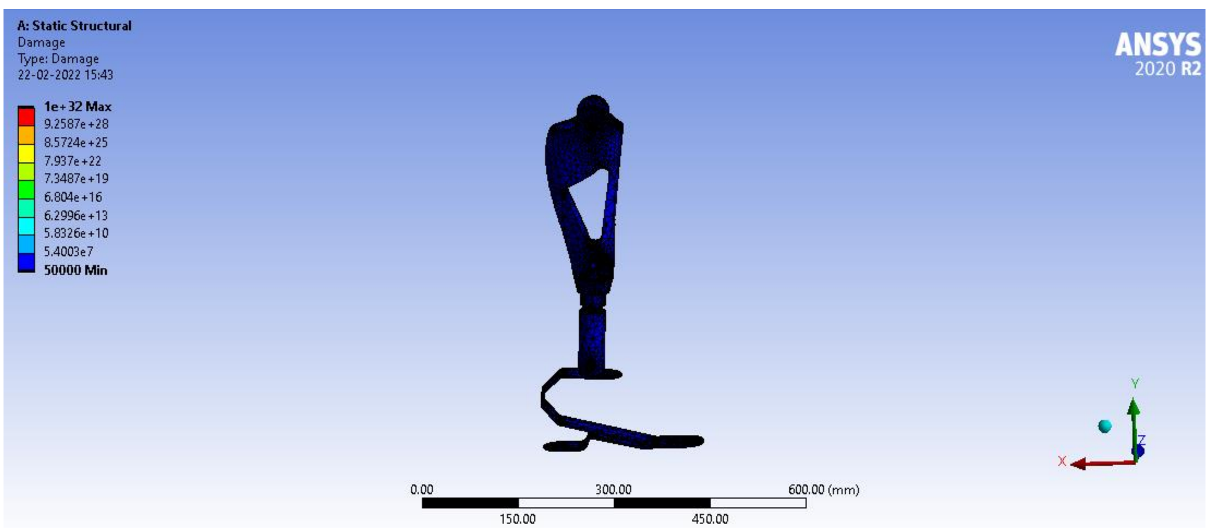


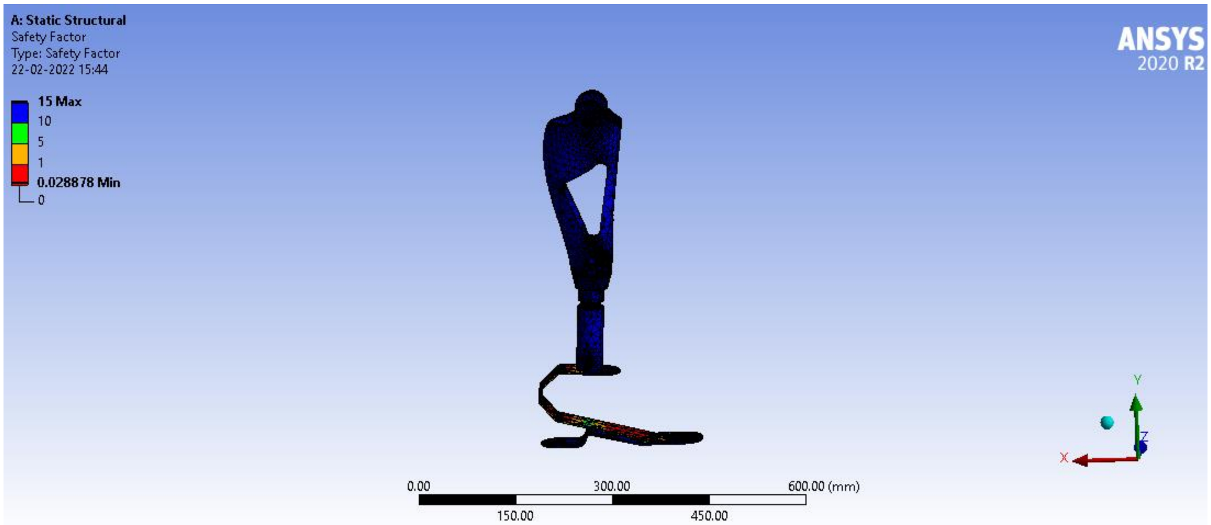

A: Static Structural
Damage
Type: Damage
22-02-2022 15:41
1e+32 Max
9.2587e+28
8.5724e+25
7.937e+22
7.3487e+19
6.804e+16
6.2996e+13
5.8326e+10
5.4003e7
50000 Min
ANSYS
2020 R2
0.00
300.00
600.00 (mm)
150.00
450.00
Y
Z
X


A: Static Structural
Safety Factor
Type: Safety Factor
22-02-2022 15:42
15 Max
10
5
1
2.502e-7 Min
0
ANSYS
2020 R2
0.00
300.00
600.00 (mm)
150.00
450.00
Y
Z
X

f) Carbon fiber

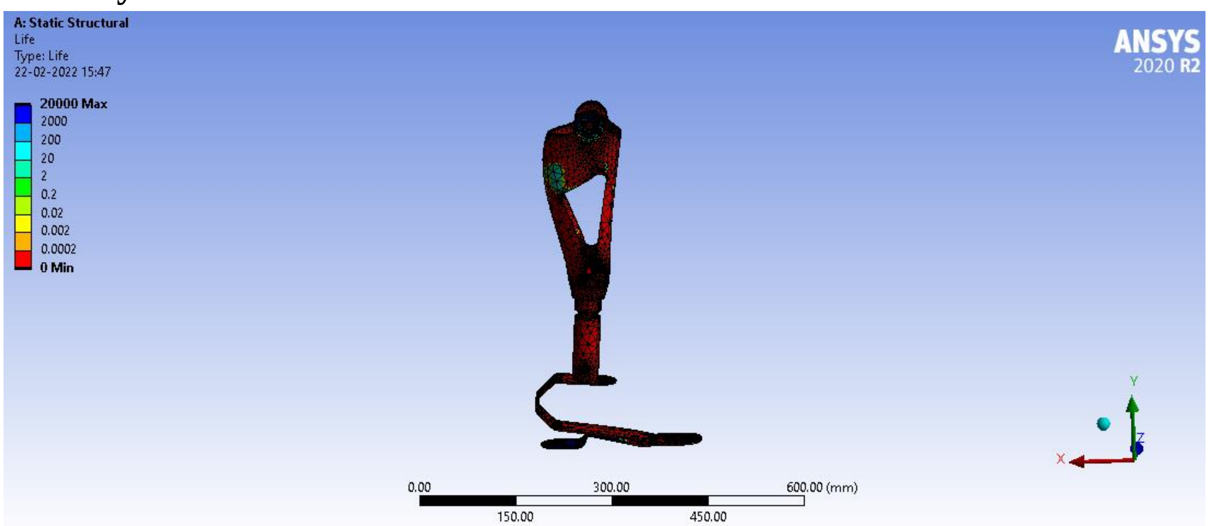


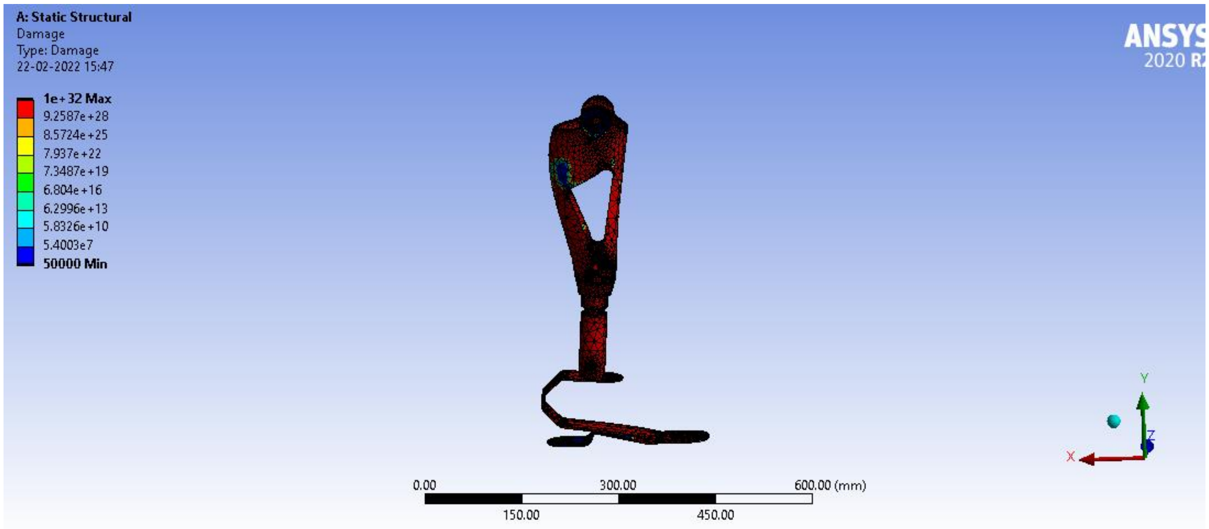


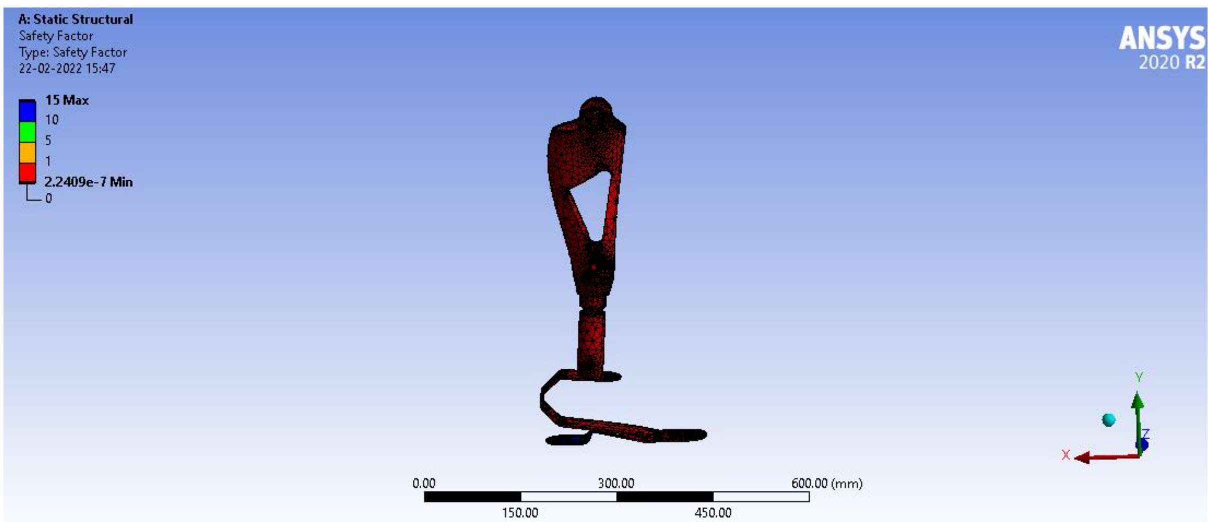


Load =80 Kg =784.8N

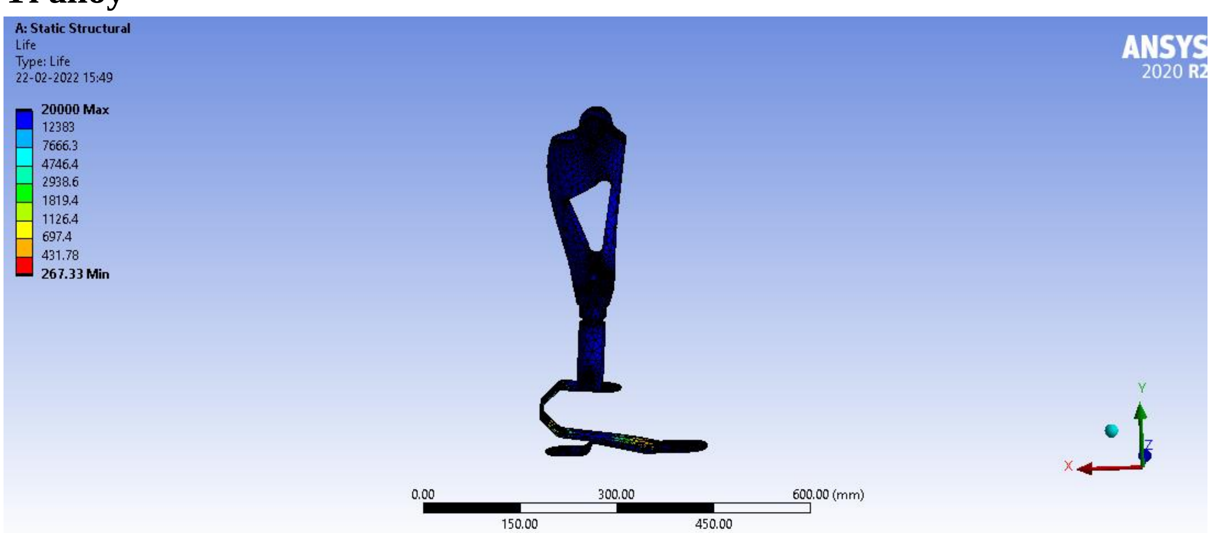
a) Al Alloy

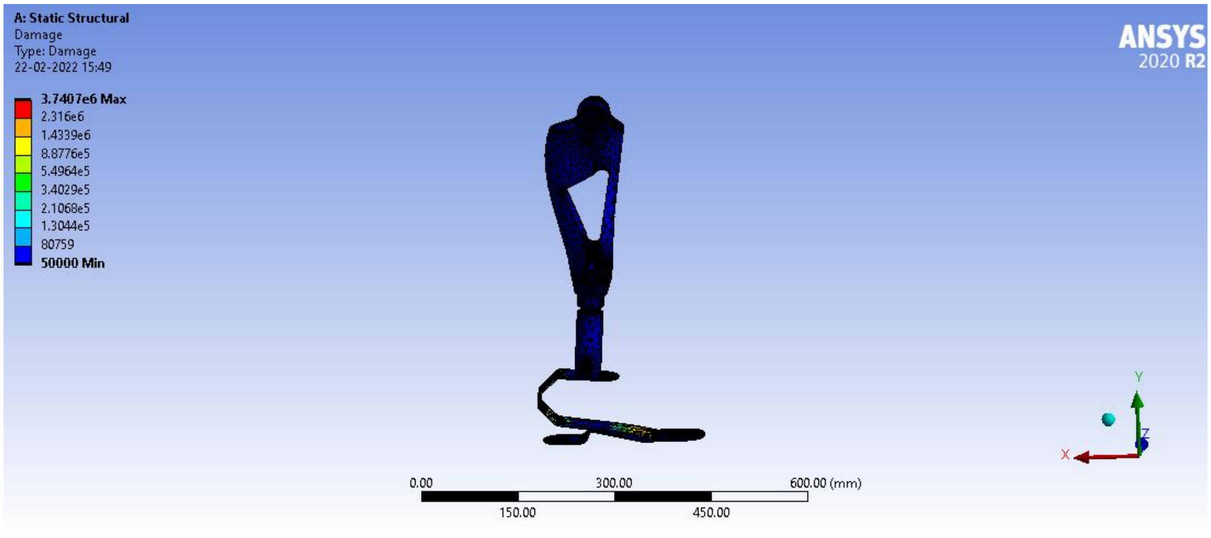


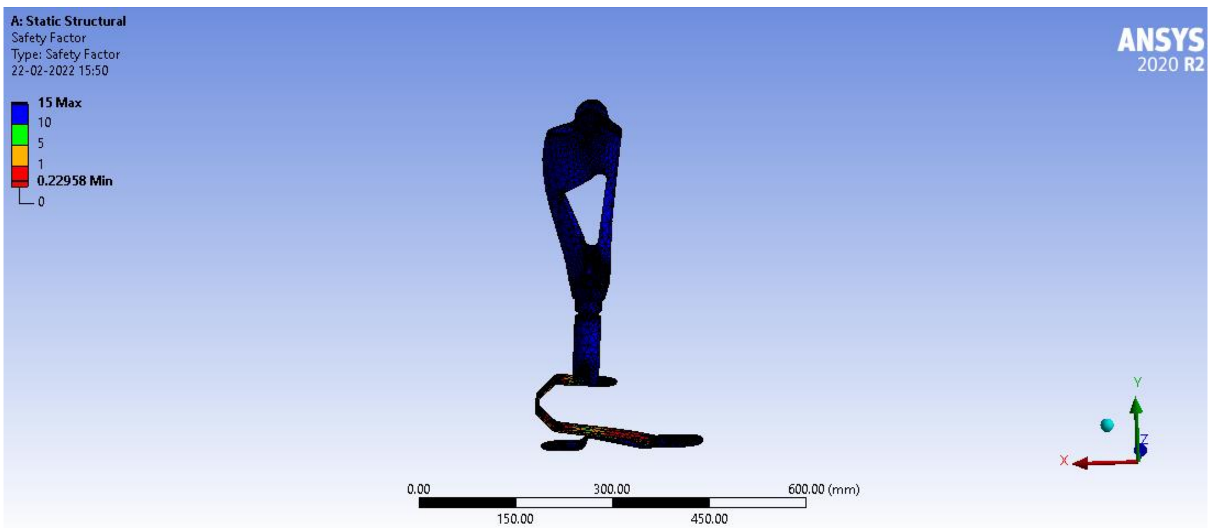

A: Static Structural
Damage
Type: Damage
22-02-2022 15:47
1e+32 Max
9.2587e+28
8.5724e+25
7.937e+22
7.3487e+19
6.804e+16
6.2996e+13
5.8326e+10
5.4003e7
50000 Min
0.00
300.00
600.00 (mm)
150.00
450.00


A: Static Structural
Safety Factor
Type: Safety Factor
22-02-2022 15:47
15 Max
10
5
1
2.2409e-7 Min
0
0.00
300.00
600.00 (mm)
150.00
450.00

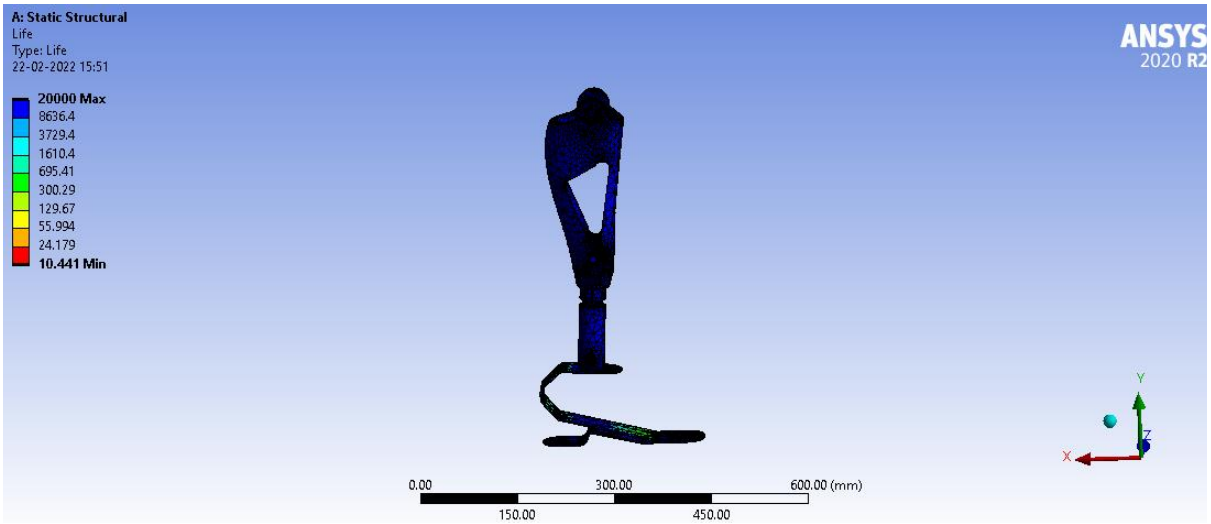
b) Ti alloy

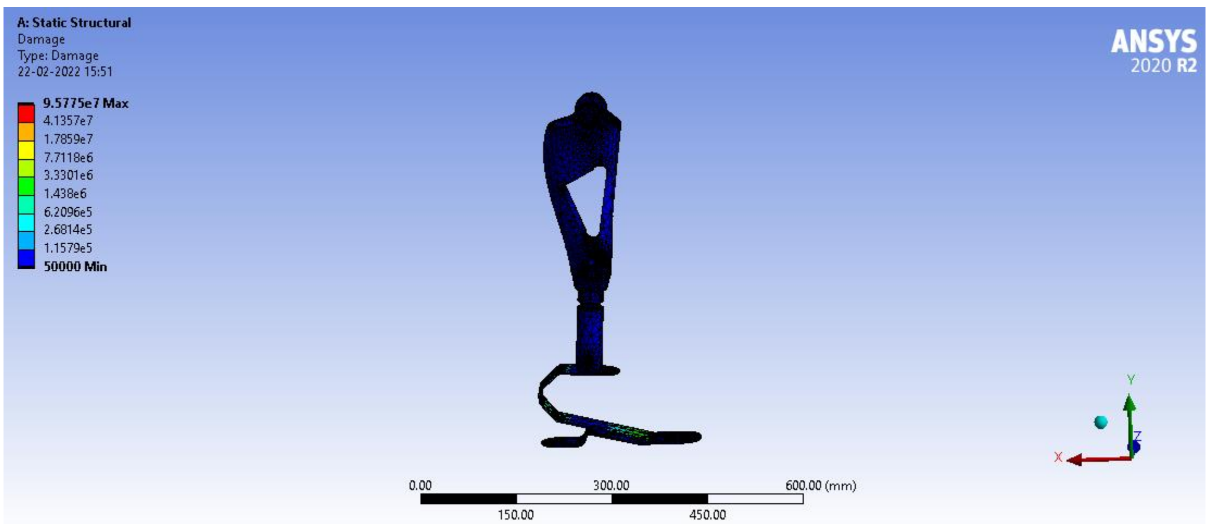

A: Static Structural
Life
Type: Life
22-02-2022 15:49
20000 Max
12383
7666.3
4746.4
2938.6
1819.4
1126.4
697.4
431.78
267.33 Min
0.00
300.00
600.00 (mm)
150.00
450.00

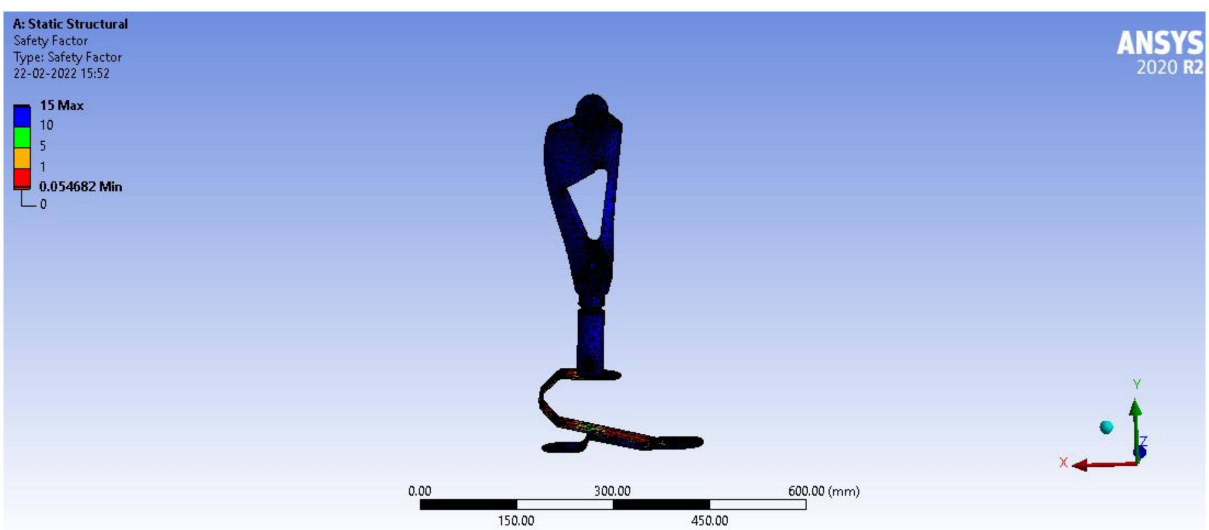

A: Static Structural
Damage
Type: Damage
22-02-2022 15:49
3.7407e6 Max
2.316e6
1.4339e6
8.8776e5
5.4964e5
3.4029e5
2.1068e5
1.3044e5
80759
50000 Min
ANSYS
2020 R2
0.00
300.00
600.00 (mm)
150.00
450.00
Y
Z
X


A: Static Structural
Safety Factor
Type: Safety Factor
22-02-2022 15:50
15 Max
10
5
1
0.22958 Min
0
ANSYS
2020 R2
0.00
300.00
600.00 (mm)
150.00
450.00
Y
Z
X

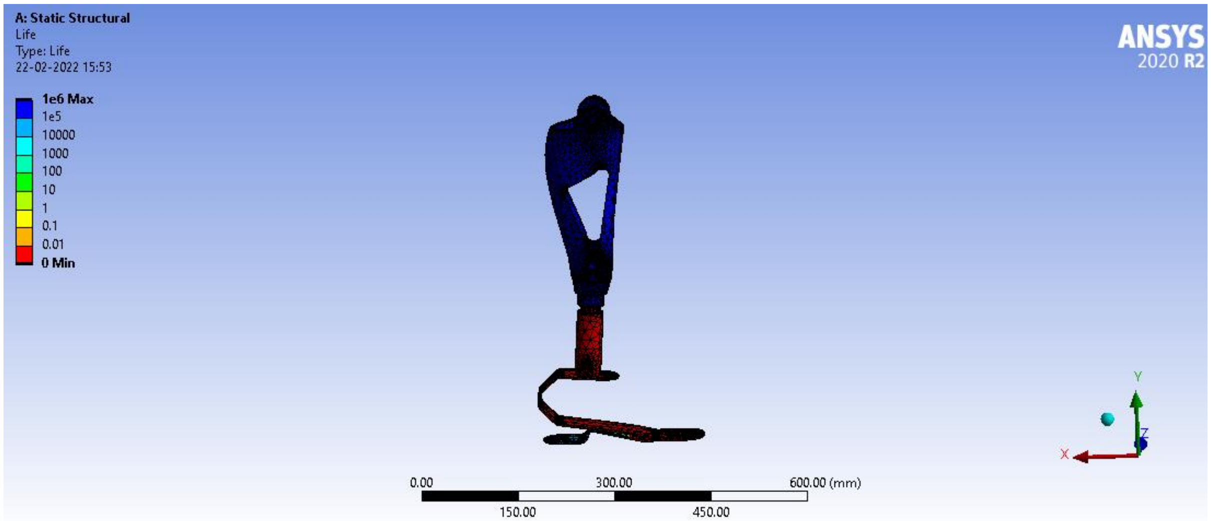
c) Carbon epoxy UD

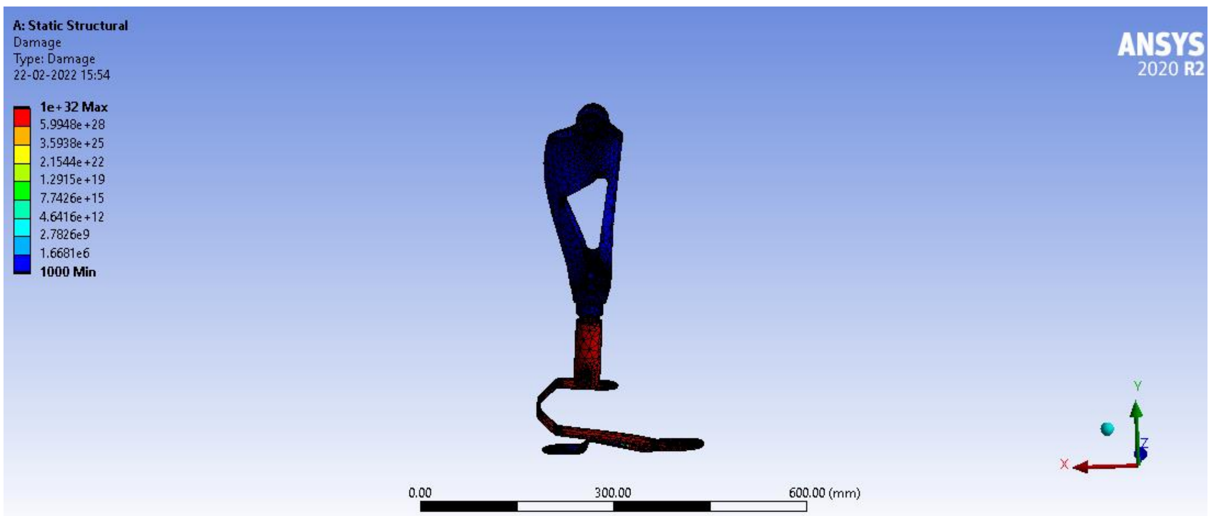


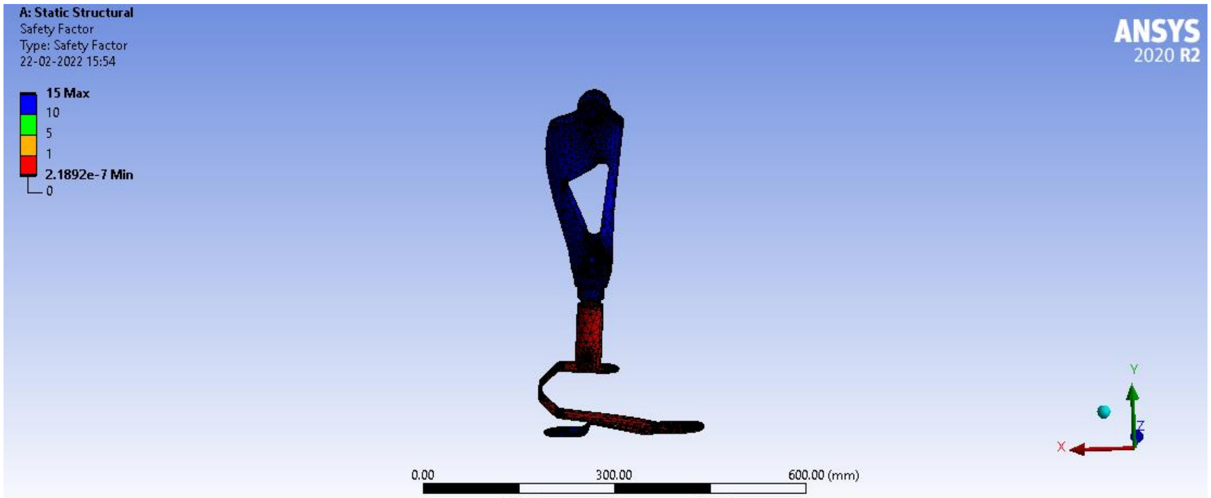




d) Structural steel

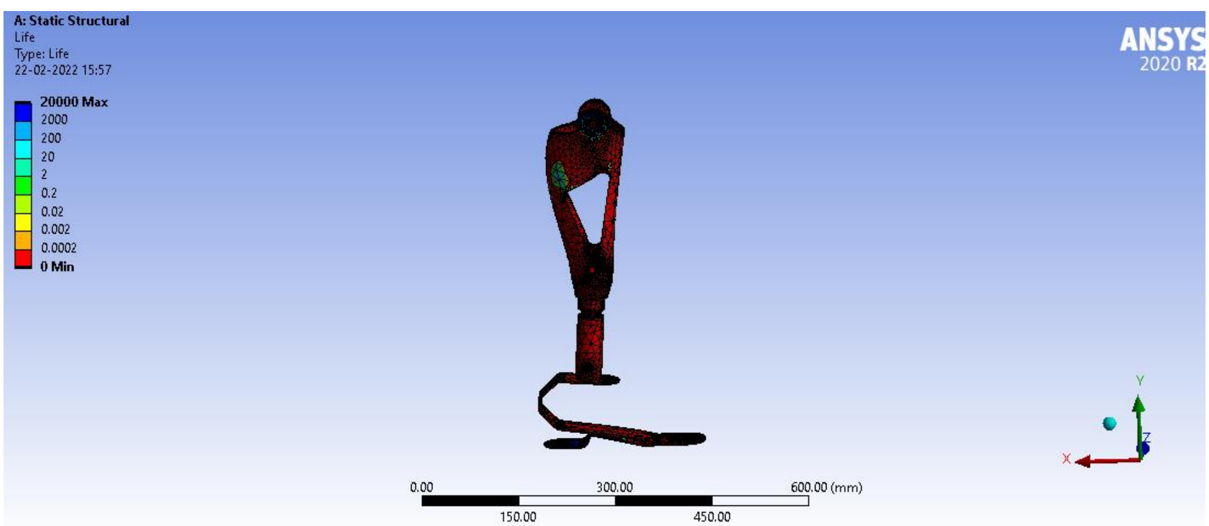


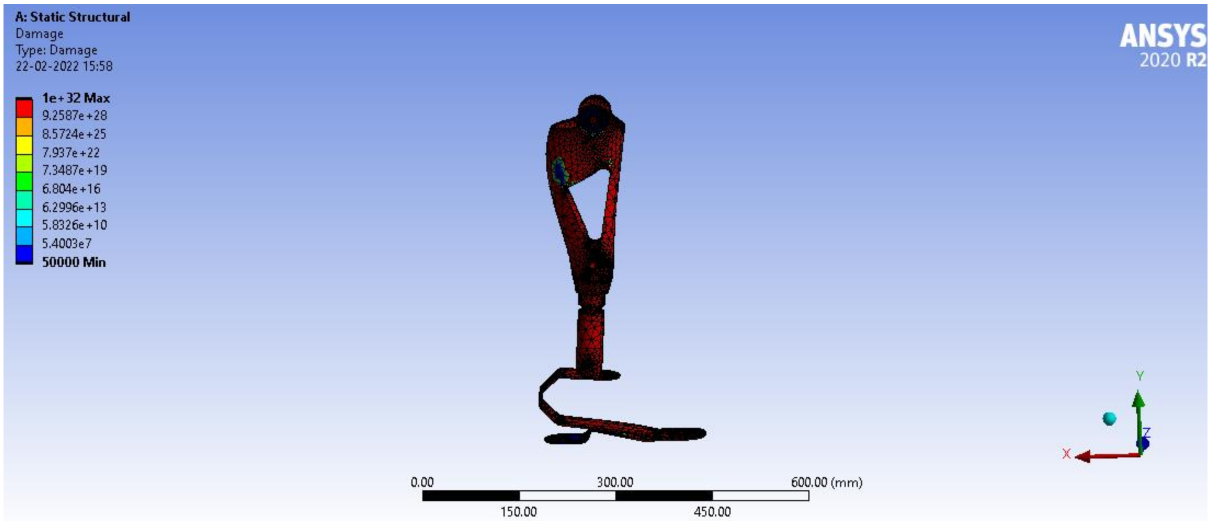


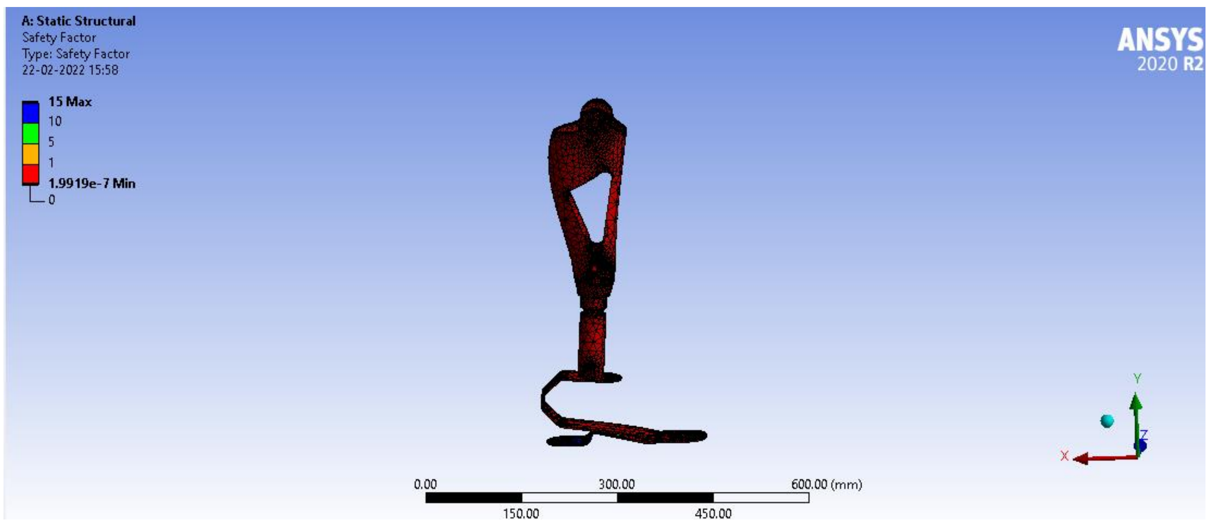


Load 90 Kg = 882.9N

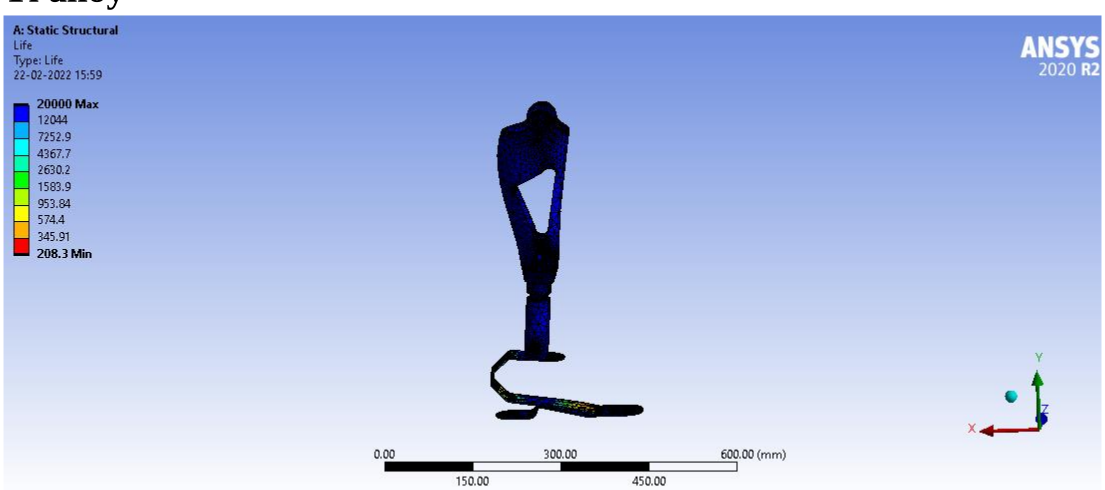
a) Al Alloy

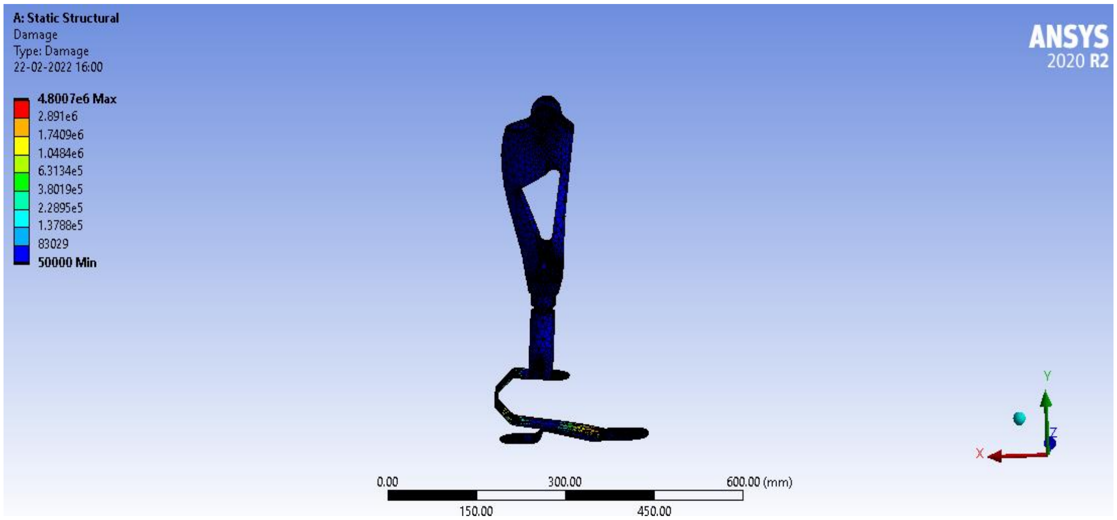


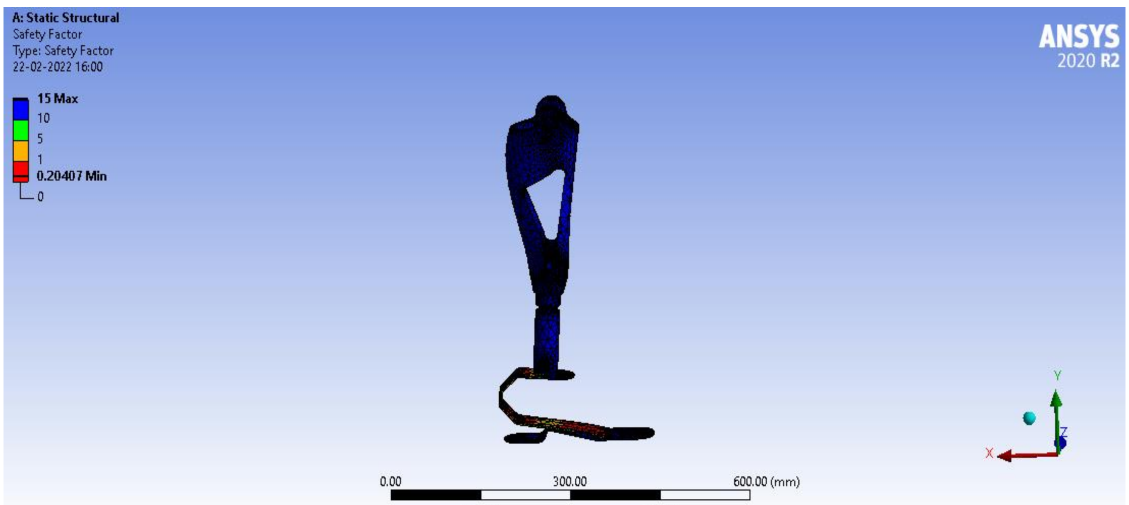

A: Static Structural
Damage
Type: Damage
22-02-2022 15:58
1e+32 Max
9.2587e+28
8.5724e+25
7.937e+22
7.3487e+19
6.804e+16
6.2996e+13
5.8326e+10
5.4003e7
50000 Min
ANSYS
2020 R2
0.00
300.00
600.00 (mm)
150.00
450.00


A: Static Structural
Safety Factor
Type: Safety Factor
22-02-2022 15:58
15 Max
10
5
1
1.9919e-7 Min
0
ANSYS
2020 R2
0.00
300.00
600.00 (mm)
150.00
450.00

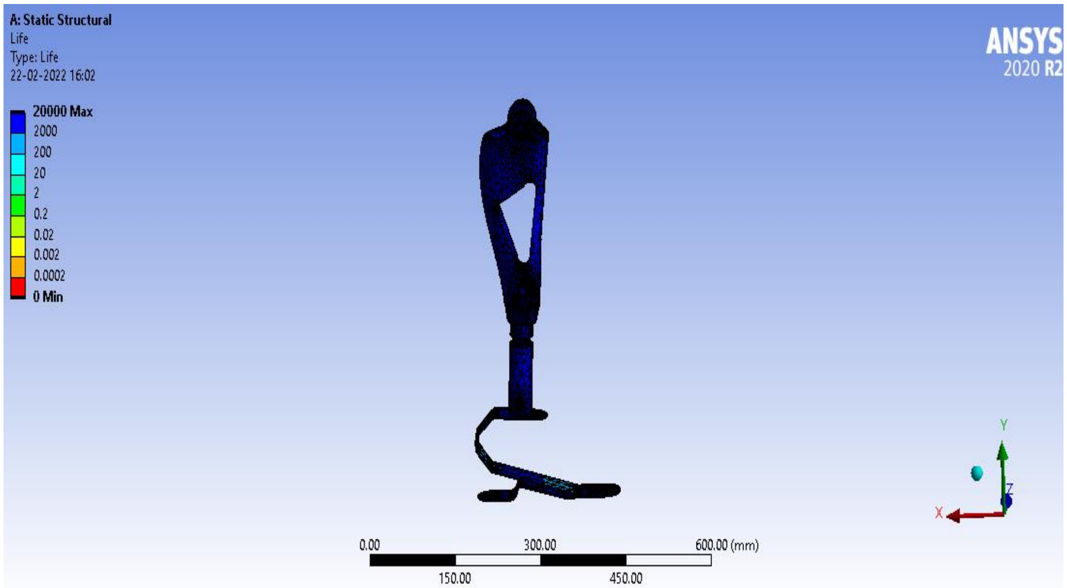
b) Ti alloy

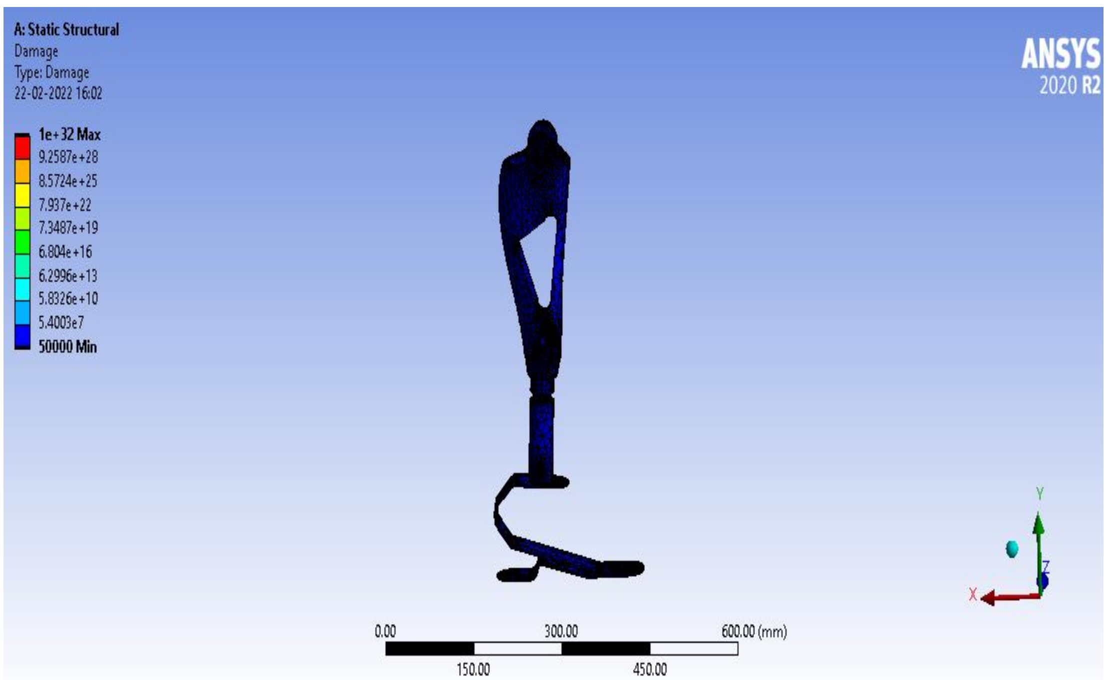

A: Static Structural
Life
Type: Life
22-02-2022 15:59
20000 Max
12044
7252.9
4367.7
2630.2
1583.9
953.84
574.4
345.91
208.3 Min
ANSYS
2020 R2
0.00
300.00
600.00 (mm)
150.00
450.00

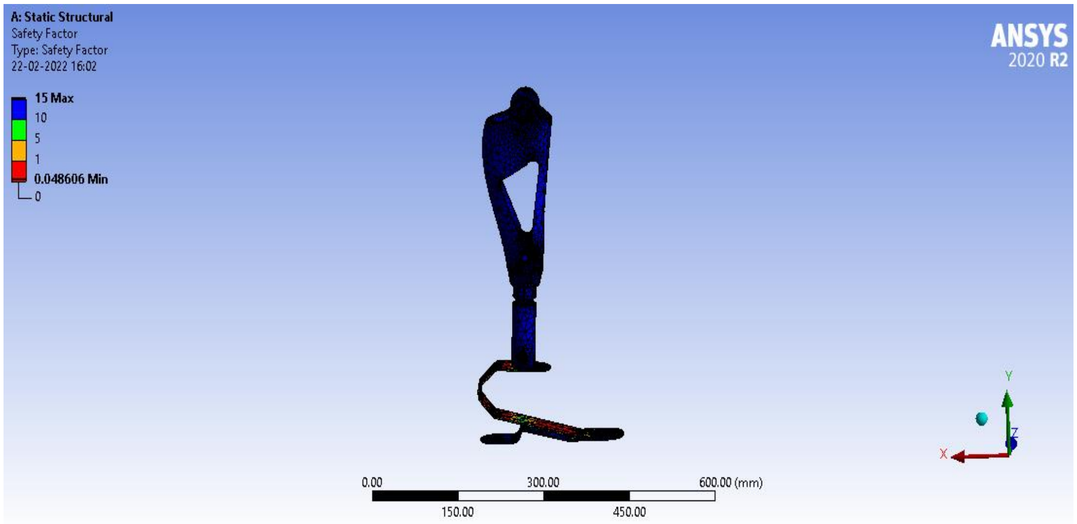

A: Static Structural
Damage
Type: Damage
22-02-2022 16:00
4.8007e6 Max
2.891e6
1.7409e6
1.0484e6
6.3134e5
3.8019e5
2.2895e5
1.3788e5
83029
50000 Min
ANSYS
2020 R2
0.00
300.00
600.00 (mm)
150.00
450.00


A: Static Structural
Safety Factor
Type: Safety Factor
22-02-2022 16:00
15 Max
10
5
1
0.20407 Min
0
ANSYS
2020 R2
0.00
300.00
600.00 (mm)
150.00
450.00

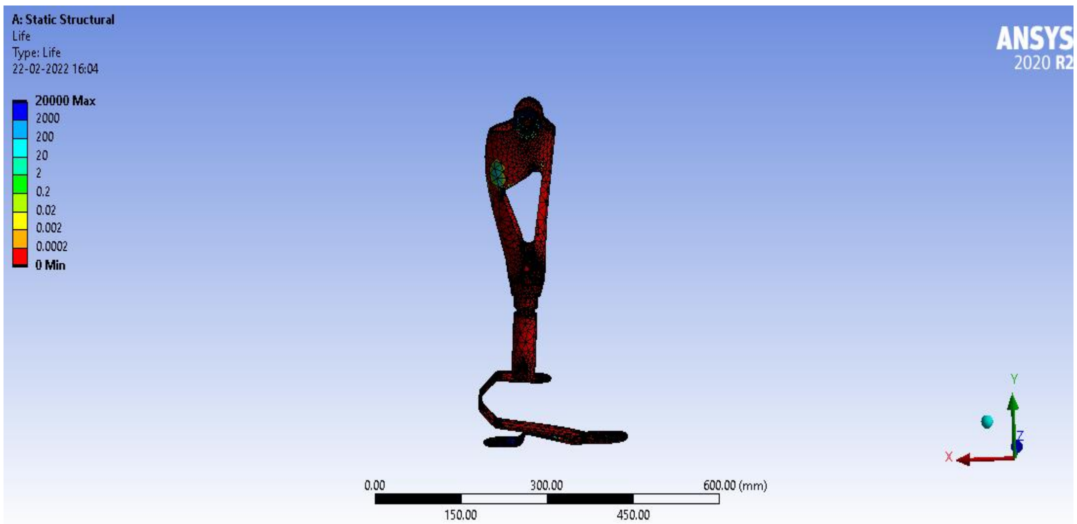
c) Carbon fiber epoxy UD 395

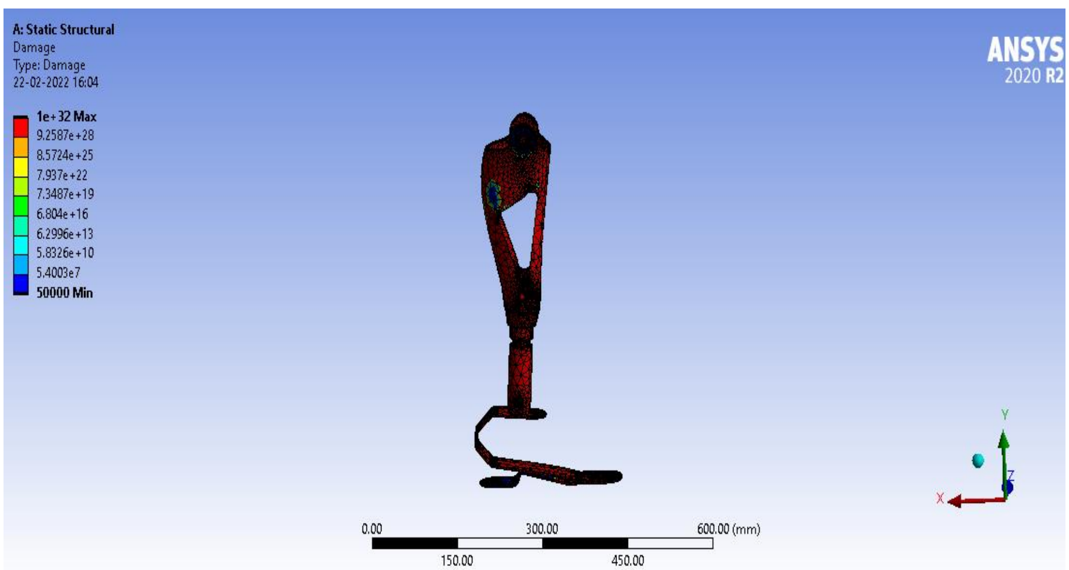


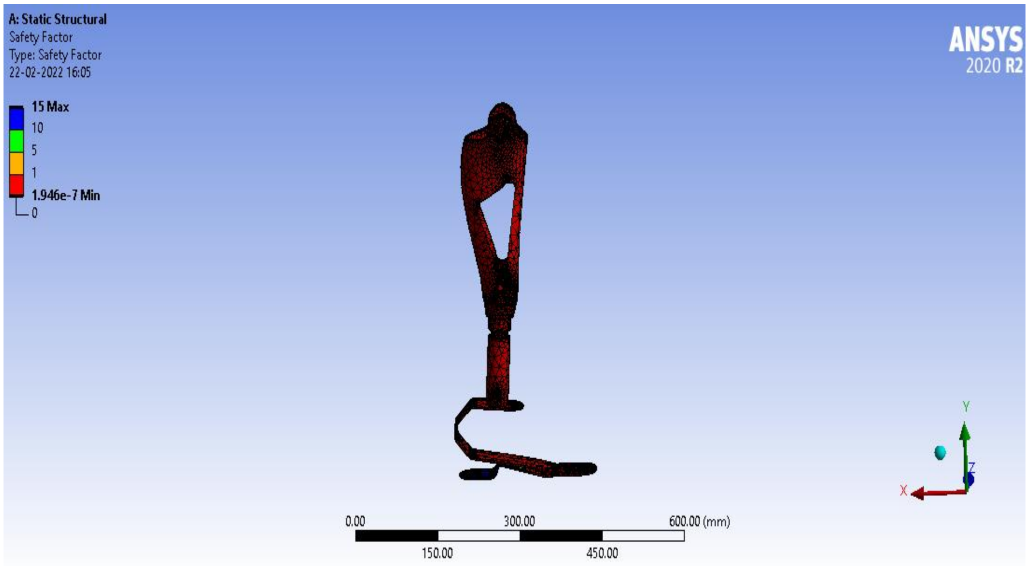




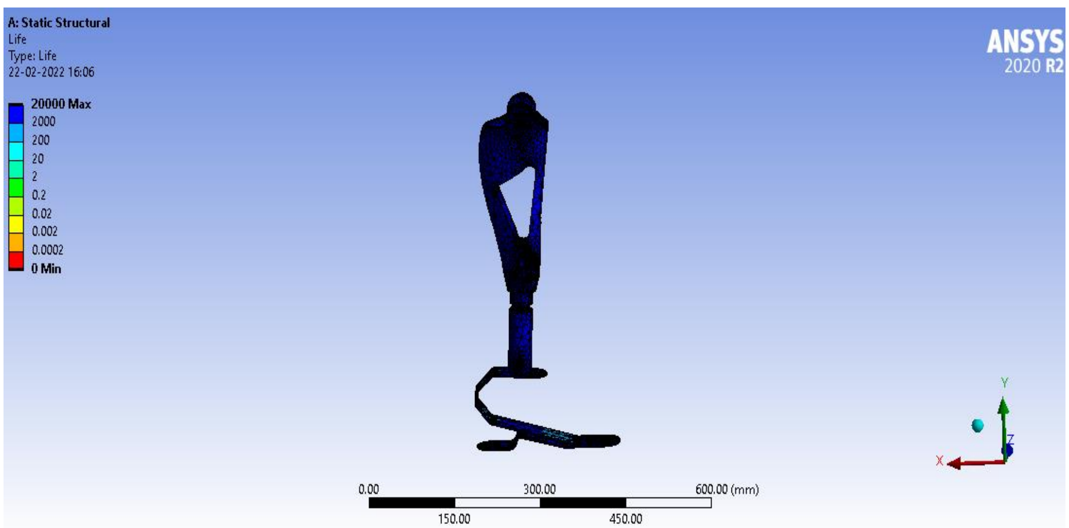
d) Structural steel

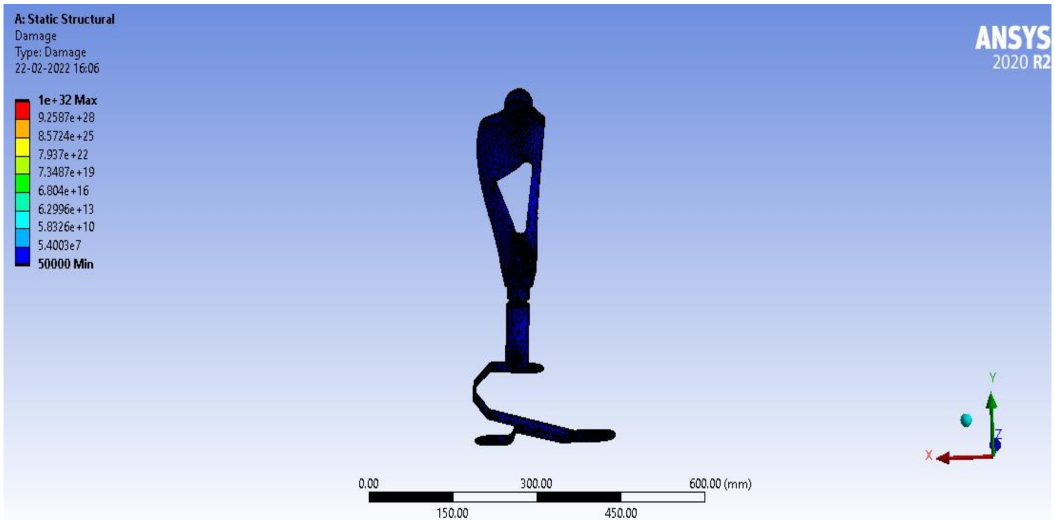


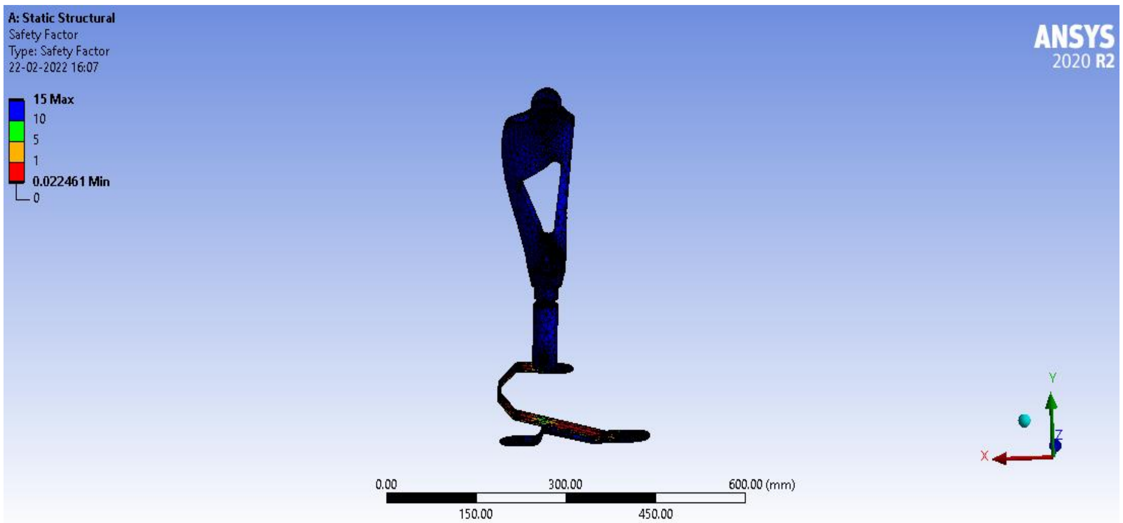




e) Carbon fiber 395GPa

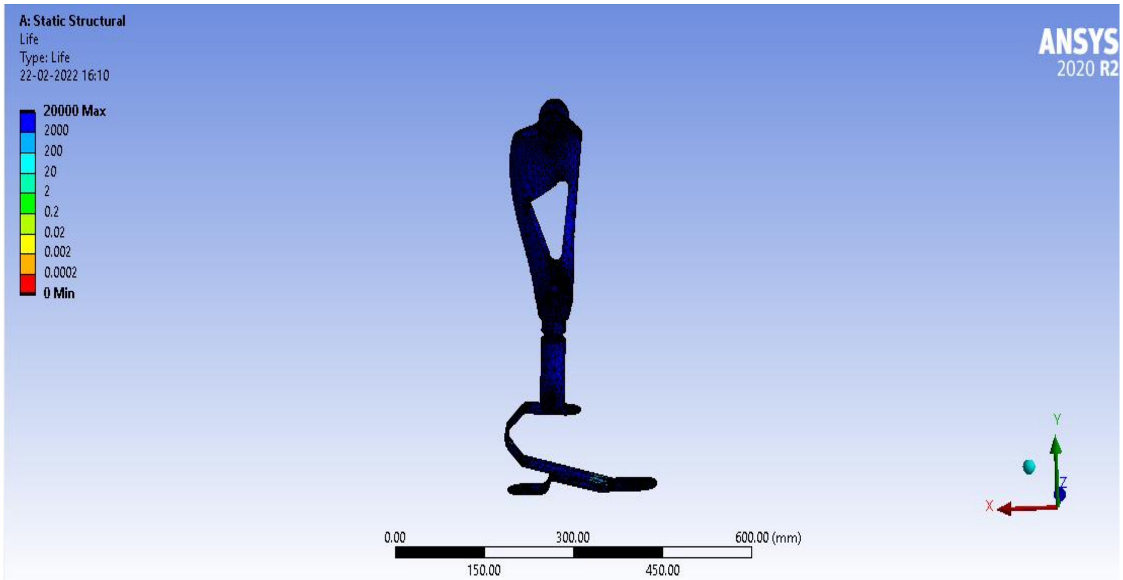


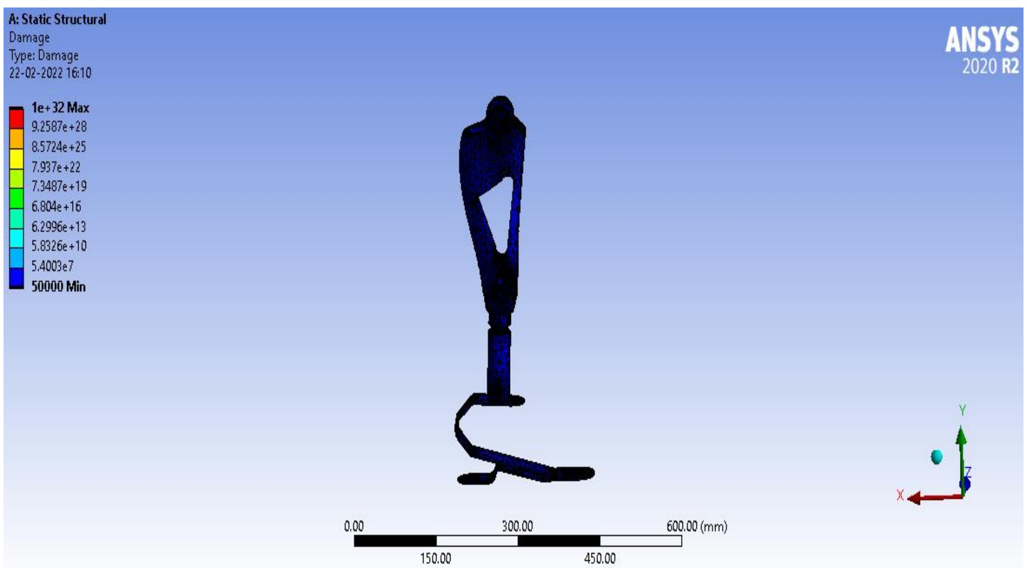


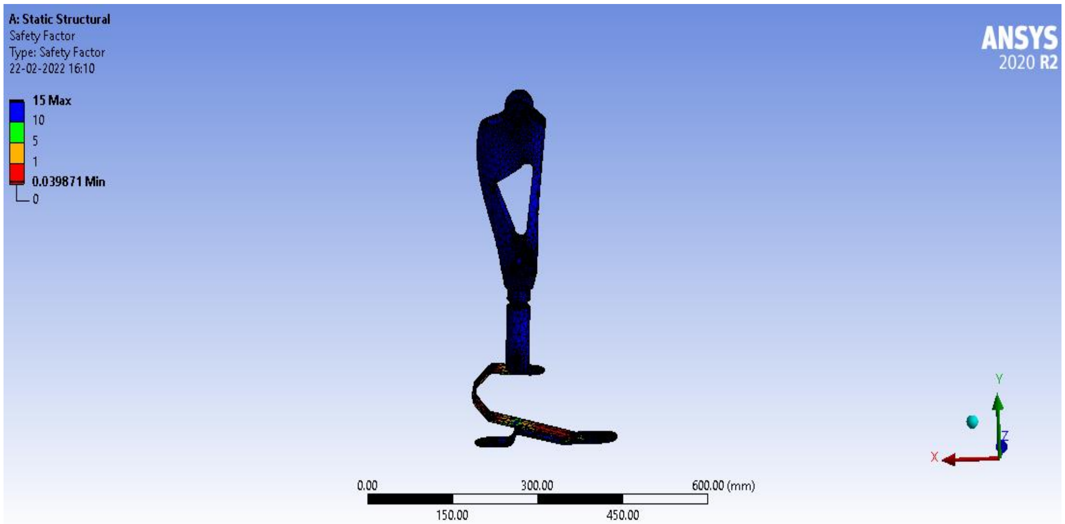


Combination

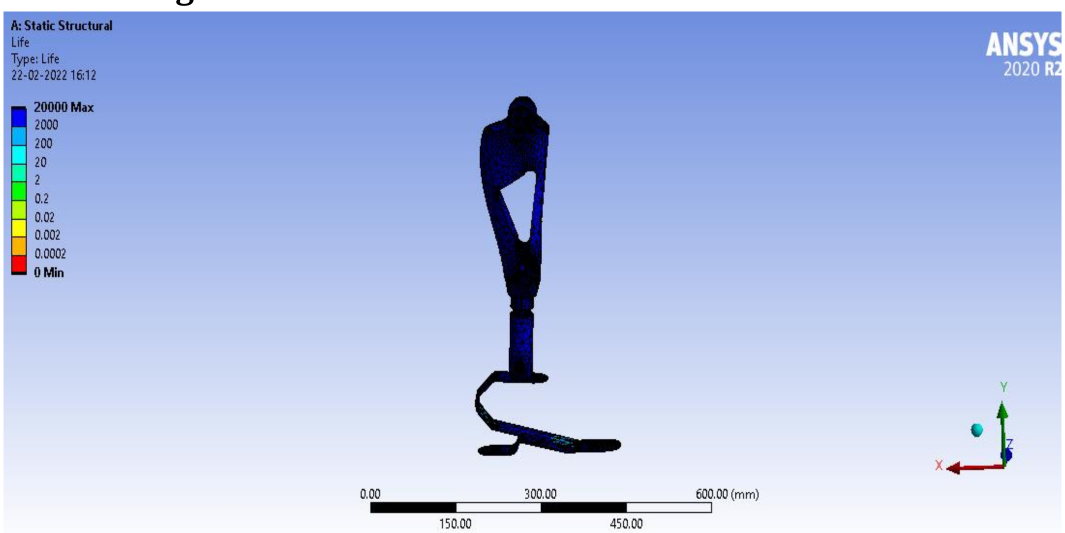
Load =60kg=588.6

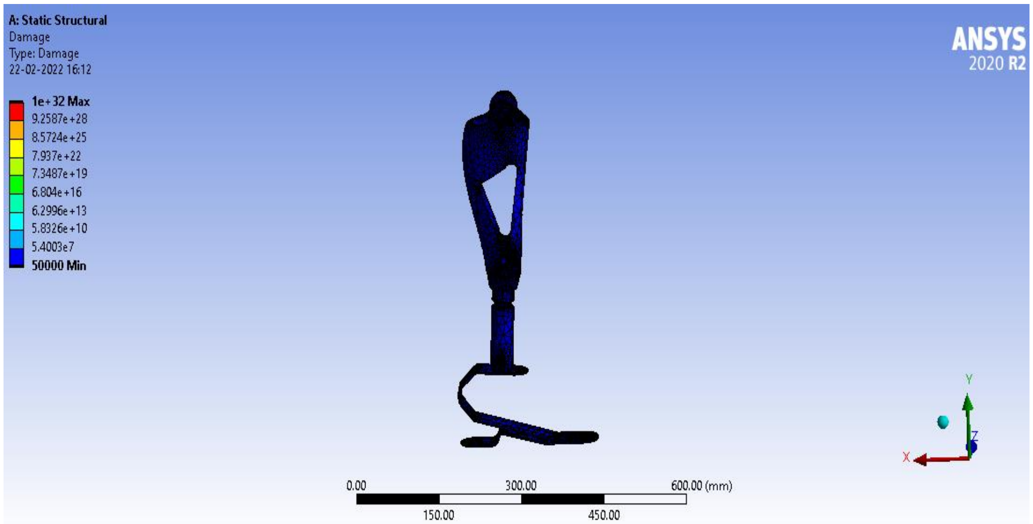

A: Static Structural
Life
Type: Life
22-02-2022 16:10
20000 Max
2000
200
20
2
0.2
0.02
0.002
0.0002
0 Min
ANSYS
2020 R2
0.00
300.00
600.00 (mm)
150.00
450.00

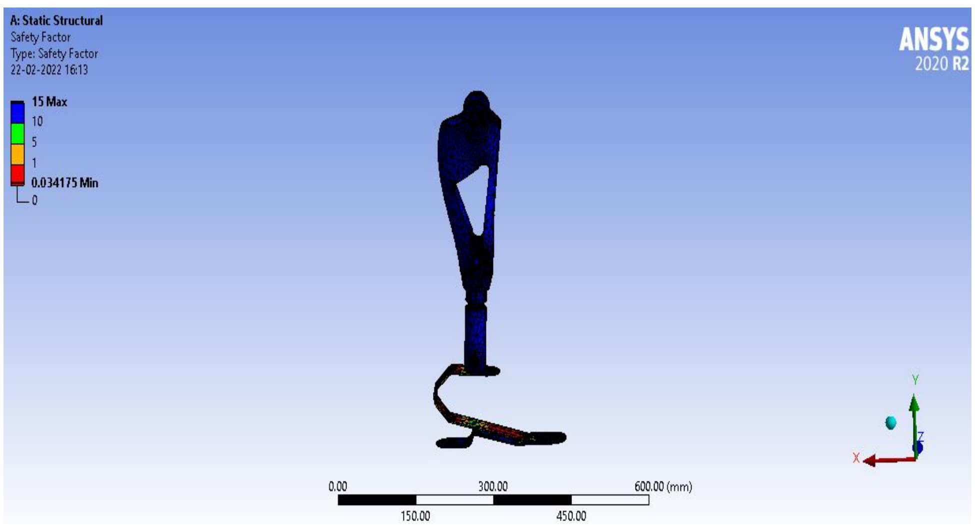

A: Static Structural
Damage
Type: Damage
22-02-2022 16:10
1e+32 Max
9.2587e+28
8.5724e+25
7.937e+22
7.3487e+19
6.804e+16
6.2996e+13
5.8326e+10
5.4003e7
50000 Min
ANSYS
2020 R2
0.00
300.00
600.00 (mm)
150.00
450.00



Load =70kg=686.7







Load =80 kg = same

Load =90 kg = same