

DESIGN AND ANALYSIS OF KNEE BRACE TO ENHANCE THE STABILITY FOR ACL RECONSTRUCTION

Submitted in partial fulfilment of the requirements for the award of
Bachelor of Technology degree in Biomedical Engineering

By

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SATHYABAMA

**INSTITUTE OF SCIENCE AND TECHNOLOGY
(DEEMED TO BE UNIVERSITY)**

Accredited with Grade "A" by NAAC

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MAY – 2022



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BONAFIDE CERTIFICATE

This is to certify that this Project Report is the bonafide work of **Hemaprakash V K (38240009)**, **Vasanthkumar S (38240040)** who carried out the project entitle "Design and analysis of knee braces to enhance the stability for ACL reconstruction" under our supervision from **September 2021 to March 2022**.

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DECLARATION

We, Hemaprakash V K (38240009) and Vasanthkumar S (38240040) hereby declare that the Project title entitled “**Design and Analysis of knee braces to enhance the stability for ACL reconstruction**” done by us under the guidance of Ms. SINDU DIVAKARAN., M.E., (Ph.D.), Department of Biomedical Engineering is submitted in partial fulfilment of the requirements for the award of Bachelor of Technology Degree in Biomedical engineering.

DATE: 02/05/2022

PLACE: Chennai

Handwritten signature of Hemaprakash V.K. in black ink, written in a cursive style.Handwritten signature of S. Vasanth Kumar in black ink, written in a cursive style.

SIGNATURE OF THE CANDIDATES

ACKNOWLEDGEMENT

We are pleased to acknowledge our sincere thanks to **Board of Management of SATHYABAMA** for their kind encouragement in doing this project and for completing it successfully. We are grateful to them.

We convey our thanks to **Dr. T Sudhakar.,M.Sc., (Ph.D.,)** Head of the Department, Dept. of Biomedical Engineering for providing our necessary support and details at the right time during the progressive reviews.

We would like to express our sincere and deep sense of gratitude to our Project Guide **Ms.Sindu Divakaran., M.E., (Ph.D.,)** for her valuable guidance, suggestions and constant encouragement paved way for the successful completion of my project work.

We would like to express our thanks to all **Teaching and Non-teaching staff** members of the Department of Biomedical Engineering who were helpful in many ways for the completion of the project.

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ABSTRACT

Injury to the knee such as ACL injury, fractures, torn meniscus, knee bursitis, patellar tendinitis is the most common injuries. Sports such as soccer, football, and skiing have been reported to be high-risk sports that can cause injury to the ACL when compared to other sport activities. Due to the high incidence of ACL injuries, approximately 100,000 ACL reconstructions are performed each year. Although conservative treatment can potentially be successful in the appropriate population, patients with goals of returning to high levels of sport activity may not be successful with conservative treatment. After the ACL reconstructive surgery the doctor recommend a Knee Braces for the patient to enhance the patient stability. Our aim is to use Acetylsalicylic acid as a bio- compatible and bio-material for knee cap. Rhinoceros software is used to design the knee cap. Ultimaker Cura software and 3D printer is used to simulate the knee cap in viable environment such that there is no miscible after the implementation. The 3D printed methodology used here is Fused Deposition Modelling (FDM). ASA is a Bio-inert and Bio-compatible amorphous thermoplastic. It is used for general prototyping in 3D printing, where its UV resistance and mechanical properties make it an excellent material for use in fused deposition modelling printers.

Keywords: ACL, Acetylsalicylic acid, Bio-compatible, Bio-material, Ultimaker Cura, Bio-inert, Fused deposition modelling, Thermoplastic.

LIST OF ABBREVIATIONS

ACL – ANTERIOR CRUCIATE LIGAMENT

ABS – ACRYLONITRILE BUTADIENE STYRENE

ASA – ACRYLONITRILE STYRENE ACRYLATE

CAD – COMPUTER AIDED DESIGN

CAM – COMPUTER AIDED MANUFACTURING

FDM – FUSED DEPOSITION MODELLING

JPEG – JOINT PHOTOGRAPHIC EXPERTS GROUP

MCL – MEDIAL COLLATERAL LIGAMENT

NURBS – NON-UNIFORM RATIONAL BASIS SPLINE

OA – OSTEOARTHRITIS

OBJ – OBJECT FILE

PCL – POSTERIOR CRUCIATE LIGAMENT

PEEK – POLY ETHER KETONE

PETG – POLYETHYLENE TEREPHTHALATE GLYCOL

PLA – POLYLACTIC ACID

RICE – REST, ICE, COMPRESSION, ELEVATION

SKP – SKETCH UP

STL – STANDARD TESSELLATION LANGUAGE

3D – 3 DIMENSIONAL

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CHAPTER 1

INTRODUCTION

The knee joint is the largest anatomical part in human body. Knees are easily prone to damages. Sports such as soccer, football, and skiing have been reported to be high-risk sports that can cause injury to the ACL when compared to other sport activities. Due to the high incidence of ACL injuries, approximately 100,000 ACL reconstructions are performed each year. Some other common knee conditions are Chondromalacia patella, Knee osteoarthritis, Knee effusion, Meniscal tear, ACL, PCL, MCL damages, Patellar subluxation, Patellar tendonitis, Knee bursitis, Baker's cyst, Rheumatoid arthritis, Gout. Anterior Cruciate ligament (ACL) is a tissue that connects the thighbone to the shinbone. ACL gets damaged during sports such as basketball, football, skiing, tennis etc. The most common knee treatments are RICE therapy, Pain medicines, Physical therapy, Cortisone injection, Hyaluronan injection, Knee surgery, Arthroscopic surgery, ACL repair. Our aim is to construct knee brace using ASA material.

1.1 KNEE BRACES

A knee brace is an effective tool in managing the discomfort caused by knee osteoarthritis. A brace works by reduce the pain by shifting the weight off the most damaged portion of the knee. Wearing a brace can improve the ability to get around and help user to walk farther comfortably. There are various types of braces used for knee arthritis. Osteoarthritis (OA) is a complex condition involving the entire joint. The disease frequently affects one side of your knee more than the other. As the damage progresses, this malalignment worsens. A knee brace can take pressure off the part of your joint most affected by osteoarthritis and help relieve pain. ACL injuries are common among athletes because they are easily prone to ACL tear or injury when stopping suddenly and changing direction. ACL knee braces protect knees from injuries during contact sports, support an injured knee, limit knee movement, and provide relief to arthritis patients with knee pain.

Patellofemoral pain syndrome occurs when the cartilage under the kneecap is damaged. Here lightweight and flexible knee braces are used as it relief pain

which is caused under the knee cap. Generally knee braces are made from combinations of metal, foam, plastic, or elastic material and straps. It is available in many different sizes, colours, and designs.

1.2 TYPES

1.2.1 Prophylactic Knee Braces

Prophylactic knee braces are designed to prevent and reduce the severity of ligamentous injuries to the knee. It is most commonly designed and used by athletes who play contact sports such as football. Prophylactic knee braces protect the MCL (medial collateral ligament) against valgus knee stresses, while also protecting the knee joints from being injured again. The prophylactic knee brace is shown in Fig 1.1. These knee braces are great for athletes of contact sports at high risk for MCL injury, or who previously suffered an MCL injury. Two of our top prophylactic knee bracing options includes this ACL (Sanders T L, et al., 2019) sports brace and range of motion knee stabilizer. It is designed to protect uninjured knees from valgus stresses that could damage the medial collateral ligaments. It is very popular among athletes.



Fig: 1.1: *Prophylactic knee brace*

1.2.2 Functional Knee Braces

A functional knee brace (Trevor B, et al., 2008) is used to provide support to knees that are already injured, either from playing a sport or a fall. Functional knee braces are also great for reducing rotation following an ACL injury or tear, and for those who need additional support after ACL repair surgery. In some cases, they can also be used to support mild to moderate PCL or MCL instability (Linda R, et al., 2005). The Functional knee brace is shown in Fig 1.2.



Fig: 1.2: *Functional knee brace*

1.2.3 Rehabilitative Knee Braces

Rehabilitative knee braces help in limiting potentially harmful knee movements while a person is rehabilitating after a recent knee surgery or an injury. These types of braces work to protect a reconstructed or repaired ligament and allow early motion of the knee joint. The Rehabilitative knee brace is shown in Fig 1.3. Rehabilitative knee braces are also a great tool to protect the knee joints and ligaments to prevent future or recurring injury.



Fig: 1.3: Rehabilitative knee brace

1.2.4 Unloader/Offloaded Knee Braces

Unloader/Offloader knee braces (Wilson B, et al., 2011) are designed to provide relief to people who have arthritis in their knees, specifically individuals who suffer from medial compartment knee osteoarthritis. Generally, they shift the weight from the damaged part of the knee to a strongest area. These knee braces are designed to unload stress (Kay M. Crossley, et al., 2015) from the affected joint by placing pressure on the thigh bone. This forces the knee to bend away from the painful area. The Unloader knee brace is shown in Fig 1.4. These braces (Stephen W Hutchins, et al., 2014) such as our osteoarthritis knee brace, can also be helpful for people who are waiting to have knee replacement surgery and want to take stress off their knees beforehand.



Fig: 1.4: Unloader knee brace

1.3 RISKS

- **Discomfort while wearing the knee brace** - A knee brace may feel bulky, heavy and hot at first. Poor fit can cause it to drop or slip.
- **Skin irritation or swelling** - The skin under the brace might become red and irritated if the knee brace does not fit properly. It may cause swelling around the joint.
- **Lack of benefit** - Studies of knee braces for people with osteoarthritis have been limited, and results have been mixed. Some people see no benefit. Others report diminished pain and increased function.
- **Stiffness** - Wearing a brace can cause the wearer to treat the braced knee as injured and favour the other knee, which could contribute to joint stiffness.
- In some knee braces there will be no openings in front and back side of knee braces for added breathability.
- Some knee braces are available in the fixed range of sizes. They are not customized.
- Cost of some knee braces is too high.

CHAPTER 2

LITERATURE SURVEY

Altman RD, Barnes CL, Cawley PW, Hederman B, Bijlsma JW, Berenbaum F, Lafeber FP, Blagojevic M, Jinks C, Jeffery A, Jordan KP are administered 110 surveys to all patients who were fitted for unloader knee braces for predominantly unicompartmental osteoarthritis 12 to 40 months before Alignment, arthritis severity, compartment involved, BMI, weight, age, gender, pain and function, number of refittings, and problems with the brace are the parameters which are concerned. 25% used the brace regularly. No clinical or radiographic factors considered were associated with ongoing brace use. Patients reported lack of symptomatic relief, brace discomfort, poor fit, and skin irritation as reasons for discontinuing the brace.

Stephen W Hutchins, Monireh A Bani, Sarah Curran, Andrey Aksenov conducted gait of seven patients was assessed in two conditions: without an orthosis and when wearing a new design of unloader knee orthosis. The knee adduction moment was significantly reduced ($p = 0.001$), and the speed of walking significantly increased ($p < 0.001$) when wearing the orthosis.

Kay M. Crossley David C. Ackland Natalie J. Collins demonstrated the individuals with knee OA, five to 20 years post-ACLR, were recruited for randomized studies. Patient-reported knee-related symptoms (knee pain, perceived task difficulty, confidence, stability) were assessed during hop for distance and step-down tests, while performance-based function was assessed with hopping distance under three conditions: i) no brace; ii) unadjusted brace (sagittal plane support); and iii) adjusted brace. The adjusted and unadjusted unloader braces produced immediate improvements in knee confidence during hop for distance, and knee pain during step-down. Following the four-week brace intervention, the allocated brace improved knee confidence, perceived task difficulty and stability during hop

B Wilson, H Rankin, CL Barnes conducted their experiment with 30 patients with unicompartmental osteoarthritis of the knee treated nonoperatively with an unloader brace and average follow-up of 2.7 years. Although the initial study suggested short-term benefit according to pain and function measures. The use of

an unloader brace is effective in providing short-term pain relief and improved function; however, most patients subsequently opt for total knee replacement on the symptomatic knee.

Mayo Clinic CP Pal, P Singh, S Chaturvedi, KK Pruthi and A.Vij, performed Solid scape rapid prototype systems were used in conjunction with three-dimensional computer-aided design (CAD) software to generate physical models of designs that can be directly investment-cast or used as masters for room temperature vulcanizing (RTV) silicone molding. This design is capable of withstanding a static load of 60kg and a displacement load of 100kg in software simulation.

T.L. Sanders, H. Maradit Kremers, A.J. Bryan, D.R. Larson, D.L. Dahm, B.A. Levy, E. Ageberg W.R. Dunn, K.P. Spindler demonstrated with Fifteen participants 2–10 years post ACLR performed a slow step down, single leg drop jump, and pivot turn jump with and without a proprioceptive knee brace. Knee kinematics in the sagittal (flexion – extension), coronal (abduction – adduction), and transverse (internal – external rotation) planes were collected using a 3D infrared system. Paired *t*-tests were performed to explore differences in knee angles and angular velocities. The brace reduced the peak knee external rotation angle and range of motion in the transverse plane during the pivot turn jump task, and significantly increased the maximum knee flexion angular velocity during the single leg drop jump task. The majority of participants reported that tasks were easier to perform with the proprioceptive brace than without.

Breg 360 customer care. (2016). Retrieved from knee braces: <http://www.breg.com/products/knee-bracing>. FamilyDoctor.org. (2016) this organisation performed Data acquisition, Knee Braces Model Development, Design the knee braces. Result shows the new method that can develop custom-made knee braces. The knee braces has designed in Blender software. They are several step to made completed design of knee braces such as subtract and Boolean methods. Design of knee braces has printed with 3D printer.

Y. Dessery M. Steultjens M. Mannisi B. Eskandari J. Woodburn J. Pallari experimented with Ten participants suffering from medial KOA (K-L grade ≥ 2) are included in this study. Participants undergo a 3D kinematic (*Qualysis OQUS, Gothenburg, Sweden*) and kinetic (*AMTI, Watertown, USA*) assessment whilst

walking with and without knee braces. Each participant wears two different unloader knee braces: Unloader one (*Össur, Reykjavik, Iceland*) and KNEEMO 3D printed bespoke knee brace (*Peacocks Medical Group, Newcastle upon Tyne, UK*). Preliminary results show pain relief with both knee braces. The knee adduction moment gives us information about the effectiveness of the knee braces to unload the knee joint during gait. Both knee braces seem to unload the knee joint. Finally, self-reported comfort, knee stability and aesthetics of the design provide information about future compliance with the knee braces and indicate better results with the 3D printed knee brace.

K.Anirudh Shivraj Narayan Yeole experiments reveal that injuries to knee occur in around 20 to 40% of accidents and primarily while playing sports like basketball, soccer etc. People in the age group of 20–60 years are susceptible to these injuries and in some cases even beyond this age. Wear out of cartilage is the main factor for cause of knee injury. Sudden impact on the knee leads to the dislocation of knee. Orthopedic surgeons have prescribed utilizing orthopedic aids, medicines and providing rest to the dislocated joint. Usage of knee protective pads is observed to reduce the impact force but generalized designs that are manufactured conventionally are not found to be in a satisfied state.

Lee Herrington aims to study were, first, to assess the effect of a neoprene knee brace on proprioceptive acuity of normal subjects and, second, to assess the relationships between a variety of tests of proprioceptive acuity. The neoprene sleeve significantly improved the degree of error scores in all tests. For the active tracking, test accuracy was improved by 28% ($p = 0.004$), the angle reproduction test showed a 23% increase in accuracy ($p = 0.029$), and the accuracy of the perceived angle test improved by 27% ($p = 0.035$). The findings of this study support the previous literature, which indicates that the application of a knee sleeve improves proprioceptive acuity.

Trevor B. Birmingham Dianne M. Bryant J. Robert Giffin performed with One hundred fifty patients were randomized to receive a brace ($n = 76$) or neoprene sleeve ($n = 74$) at their 6-week postoperative visit after primary ACL reconstruction with hamstring autograft. Patients were assessed preoperatively, then 6 weeks and 6, 12, and 24 months postoperatively. A functional knee brace does not result

in superior outcomes compared with a neoprene sleeve after ACL reconstruction. Current evidence does not support the recommendation of using an ACL functional knee brace after ACL reconstruction.

CHAPTER 3

AIM AND SCOPE

Current method to develop the knee braces is complicated because the manufacturer produces knee braces that not have custom size. It just has few select sizes such as small, medium, and large. Traditional knee braces have been solid structure. Knee braces can be designed using various materials like Nylon, PEEK (Polyether Ether ketone), PLA, PETG (polyethylene terephthalate glycol), ABS (Acrylonitrile Butadiene Styrene), ASA (Acetyl salicyclic Acid), and ULTOM.

Our aim is to design customized knee braces using 3D printers and to design the knee braces using ASA (Acetyl Salicyclic Acid).

CHAPTER 4

MATERIALS AND METHODS

4.1 MATERIAL

Acrylonitrile styrene acrylate (ASA), also called is an amorphous thermoplastic. It is used for general prototyping in 3D printing, as its UV resistance and mechanical properties make this material as an excellent material for to design in fused deposition modelling printers. The Chemical formula of ASA is **C₁₈H₂₃NO**. ASA is more resistant to environmental stress than ABS, especially to alcohols and many cleaning agents. It has high outdoor weatherability; it retains gloss, colour, and mechanical properties in outdoor exposure. It has good chemical and heat resistance, high gloss, good antistatic properties, and is tough and rigid. ASA is mildly hygroscopic.

4.2 METHODOLOGY

4.2.1 Fused Deposition Model

The 3D printers that work on FDM technology consist of the

- i. Printer platform
- ii. A nozzle
- iii. The raw material

Principle - FDM works on an "additive" principle by laying down material in layers.

4.2.2 Working of FDM 3D Printers

Fused Deposition Modeling (FDM) is a 3D printing technique explored in the 1990s by Stratasys.

The Printer Platform: The printer platform or the bed is typically made up of some metal, ceramic or hard plastic, and each successive layer is deposited on this bed/platform.

The Nozzle: The nozzle of FDM printers is attached to a mechanical chassis which uses belt/lead screw systems to move. The entire extrusion assembly is allowed to move in all the directions by a motorized system i.e. X, Y and Z dimensions. A fourth motor called as the stepper motor is used to advance the thermoplastic material into the nozzle. All the movements of the head and the raw material are controlled by a computer.

The Raw Material: Raw material is usually a production grade thermoplastic, also metal is sometimes used. The thermoplastic material is capable of being repeatedly melted when exposed to heat and re-solidified when the heat is withdrawn. The thermoplastic filament or a metal wire is seated as a coil on a mounted spool. It is then fed via the printer nozzle. The printers allow the temperature of the nozzle to be maintained just close to the glass transition temperature of the material being extruded. This allows the material to be extruded in a semi-liquid state, but return to solid state immediately. This results in a better dimensional accuracy.

4.2.3 The FDM 3D Printing Process:

When the FDM printer begins printing the raw material is extruded as a thin Metal/ filament through the heated nozzle. It is deposited at the bottom of the printer platform, where it solidifies. The next layer that is extruded fuses with the layer below, building the object from the bottom-up layer by layer. The FDM process is explained in below Fig 4.1. Most FDM printers first print the outer edges then the interior edges and lastly the interior of the layer as either a solid layer or as a matrix.

In some models there are some fragile and weak 'overhangs' that will hang downwards unless they are given some kind of support. An FDM printer follows a mechanism whereby some support structures are printed along with the object to support them from hanging downwards. Then they are removed once the build is complete. These support structures are of the same material as the model. Some other printers have a second extruder to deposit soluble thermoplastic support structures to prevent the overhangs from hanging. These support structure may be

of a different composition than the thermoplastic used for the 3D mode which are later dissolved by an appropriate solvent.

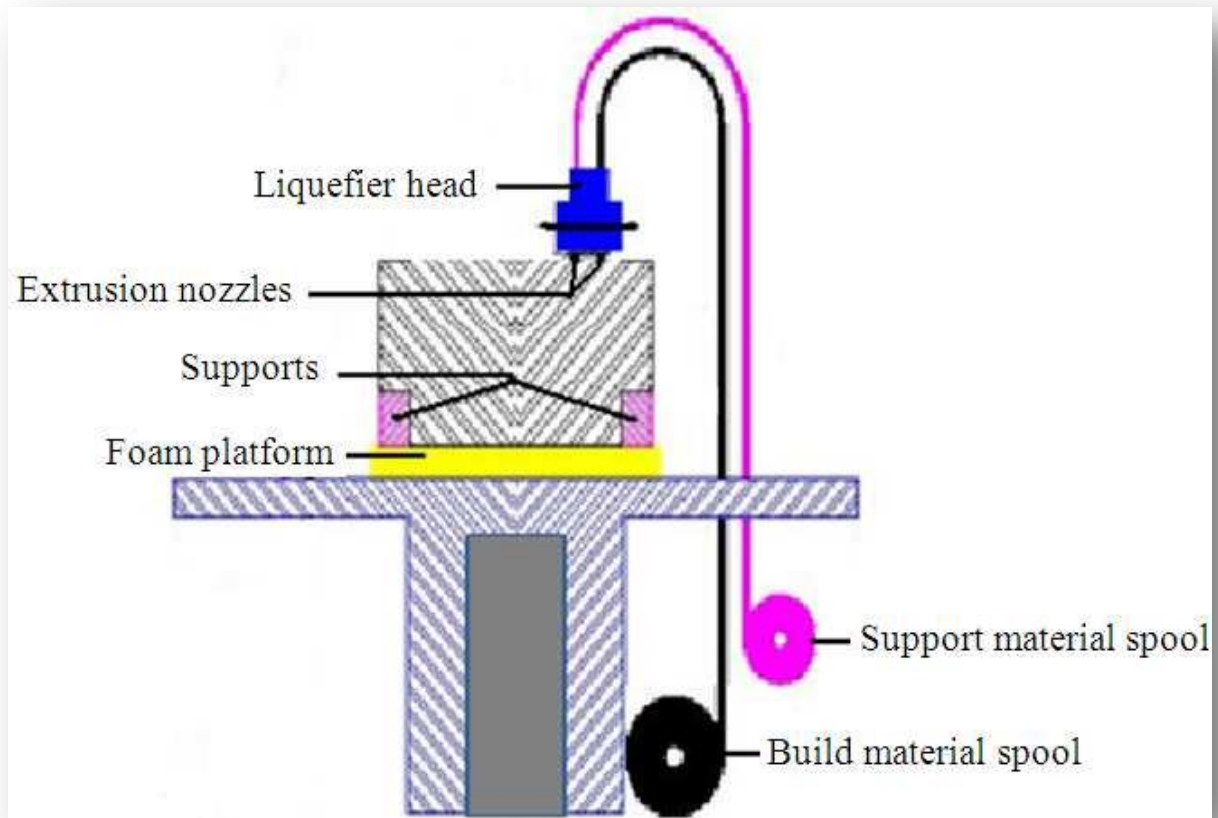


Fig: 4.1: FDM process

4.3 RHINO SOFTWARE

It is computer-aided design software. Rhino CAD is used primarily in architectural trades, industrial design, and jewellery design. From rapid prototyping to production, it can offer many advantages by this computer-aided design program.

Rhino software is developed by Robert McNeel & Associates. Rhino is developed for Microsoft Windows and Mac operating systems. Before Rhino, there used Grasshopper, a visual scripting language.

Now Rhino entirely suppresses the Grasshopper, as this programming language is currently fully integrated. Grasshopper is mainly used to build productive algorithms, such as productive art.

This 3D modeling software is an experienced program; it will allow user to develop really complicated models, geometries, algorithms.

Rhino 3D is a free form external modeler that uses the sketching by curves technique (NURBS or Non-Uniform Rational Basis Spline). NURBS is an accurate model that provides curves and surfaces in computer graphics. This mathematical model gives great flexibility and precision during the entire 3D modeling process. In this technique, user can work with the curves when designing relatively by linking polygons. User can create their three-dimensional surface by altering the curves. This kind of modeling uses adaptive mesh, which enables user to correct the number of faces forming the object's surface. This modeling procedure is the most accurate method of 3D printing.

Rhino includes a set of tools to help the user to develop real time projects, no matter what domain. User can able to find the comprehensive tools, transform tools, points and curves options, arise features, and a lot of mesh tools to export the meshes or convert NURBS to meshes for display or manifesting.

This program is not only useful for 3D generations, certainly, using the Make2D feature of Rhino will also be good for the user to create 2D models and drafts, but user will also be able to develop technical models and communicate all the impressions using both 2D and 3D.

Rhino is particularly useful for additive manufacturing, but this program can certainly be used for many different applications. It is an accurate 3D modeling software, excellent to design for engineering analysis and it also provides deep analysis and visualization features. Rhino 3D modeling software can also help user to develop great photorealistic rendering and makes animation or illustrations/models.

Design realization requires high-quality of 3D (Muhammad Hanif Ismail & Mohammed Najib Salleh, 2016) models in every phase of design, which can be achieved by this Rhino software. From presentation to analysis, and fabrication, this modeling software constantly offer new tools and enhancements to help ensure that the 3D models (Gayathry V, 2021) used during the method are the highest feasible quality.

The growth of this software started 20 years ago with the idea to provide absolute and flawless tools to marine designers to build computer prototypes that they could use to maintain the manufacturing process of their equipment. That is the beginning, a real connection between this protocol and digital manufacturing.

Illustrations built with Rhino 3D are detailed and usable for many manufacturing processes and particularly additive manufacturing.

This software is particularly adapted to industrial design and could help user with rapid prototyping and output processes. Moreover, this 3D program offers ones great freedom in their respective domains; users can totally create freeform grounds. Rhinoceros is CAD software generally used for architecture, marine design, jewellery design, automotive designs, CAD / CAM, reverse engineering, product design, as well as multimedia and visual design industries. Improving product design is easy because of this 3D modelling tool. Our designed printed model is shown in Fig 4.2.

Rhino 3D gives various functions to make CAD files printable in 3D.

Mesh: several file formats used in 3D printing use polygonal mesh in their design. The “Mesh” process available in Rhino software allows user to modify a part constructed using NURBS in a polygonal mesh. This is particularly useful in order to export the model into polygonal mesh file formats like STL and OBJ, which are accepted on Sculptor’s website.

When it appears to 3D printing (Deepa Beeta Thiya, 2021), (Jim C, 2021), the analysis tools of Rhino are very useful. User will have measurements, surfaces, geometric and other tools to ensure the prototype is prepared for 3D printing.

3D Rhino file formats

Before using additive manufacturing, user have to send out their 3D design in a format similar to professional or desktop 3D printers. The Rhino 3D file format uses the expansion (.3DM file). User can export their Rhino 3D modeling into several formats ratified on Sculpteo’s online 3D printing service. When user modeling is completed, they can then export the file into layouts such as 3DS (3D studio), DXF (AutoCAD), SKP (Sketch up) and IGES. Before doing so, make sure that user target format supports colors and compositions.

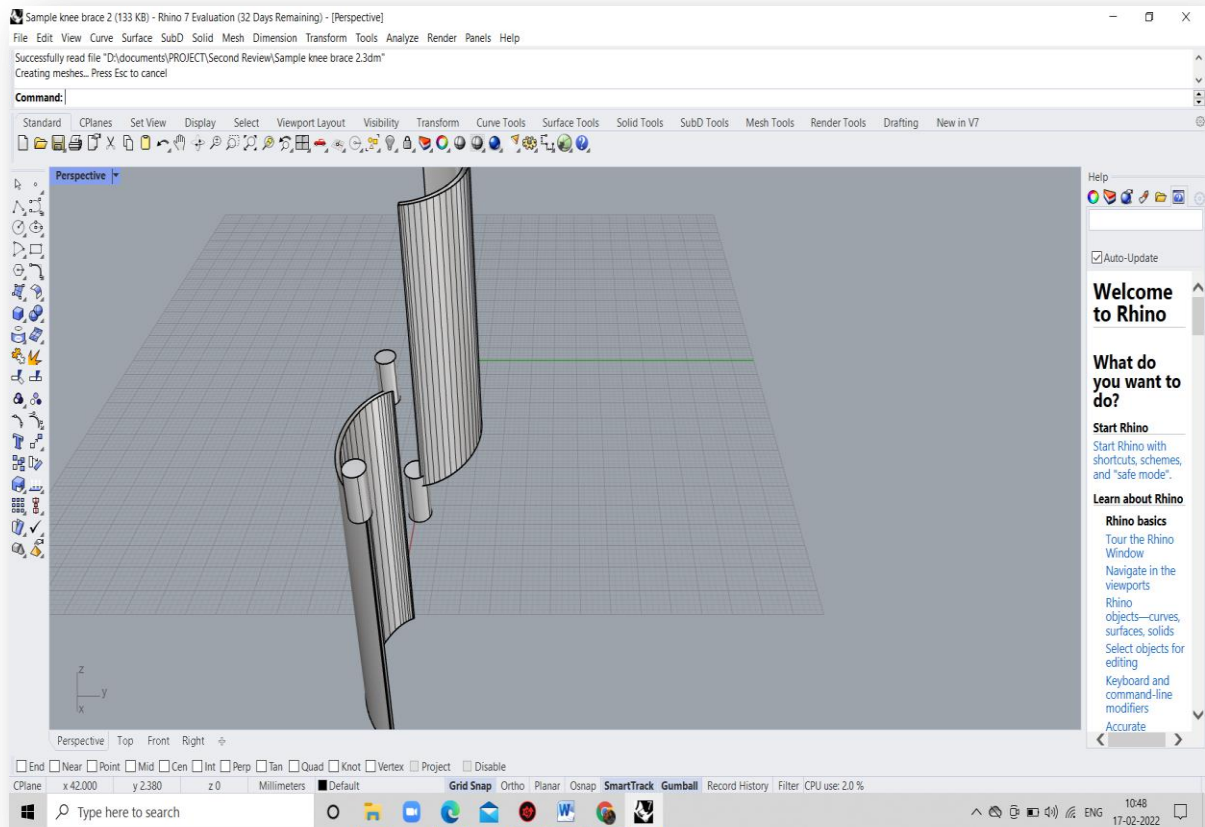


Fig: 4.2: Rhino software

4.3.1 Commands used in rhino:

- Offset – To duplicate the shapes.
- Group – To interconnect many shapes
- Extrude – To convert curves(2D) into surface (3D)
- Difference – it is used to perform Boolean operations (addition and subtraction of volumes). This way, user can build closed volumes suitable for 3D printing.
- Join - In 3D printing, two parts of an object must be connected in order to obtain a single object. Using the “join” function integrate the intersections of two volumes in order to create a single object.
- Test Solid - A model can only be printed if the modelled object is closed. This function will identify “open” modelling”. The “Show Edges” command will help you locate the open sides so the modelling can be easily corrected.

4.4 MEASUREMENTS

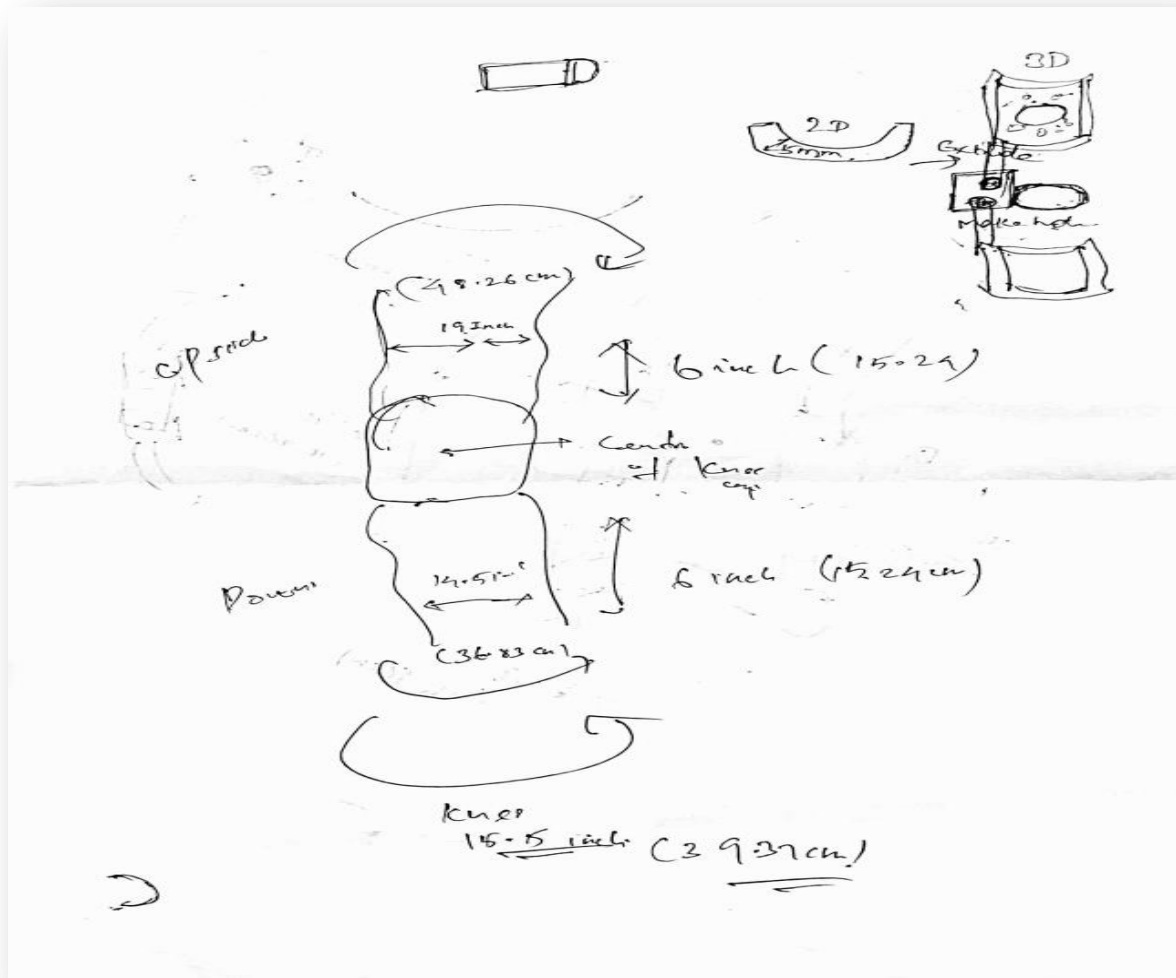


Fig: 4.3: Measurement sketch

At first centre of knee is spotted. Then six inch and above and six inches below is measured. Then the circumference of the upper part and lower part is measured. Then the circumference of the centre of the knee is measured. Here the individual (Hemapakash-38240009) knee size is measured and shown in Fig 4.3. Individual upper circumference is 48.26 cm which is of 19 inch and bottom circumference is 36.83 cm which is of 14.5 inch. The centre part circumference is 39.37 cm which is of 15.5 inch.

4.5 MECHANICAL STIMULATION

The slicing and stimulation parts are done under the Cura software. Cura is an open source slicing application for 3D printers. It was created by David Braam.

The Development is hosted on GitHub. User can also view their designed model in top which is Fig 4.5, bottom which is Fig 4.4, side which is Fig 4.6, front and back side. Ultimaker Cura works by slicing the user's model file into layers and generating a printer-specific g-code and once finished, the g-code can be sent to the printer for the design of the 3D object. The open source software, compatible with most desktop 3D printers, can work with files in the most common 3D formats such as STL, OBJ, X3D, 3MF as well as image file formats such as BMP, GIF, JPG, and PNG.

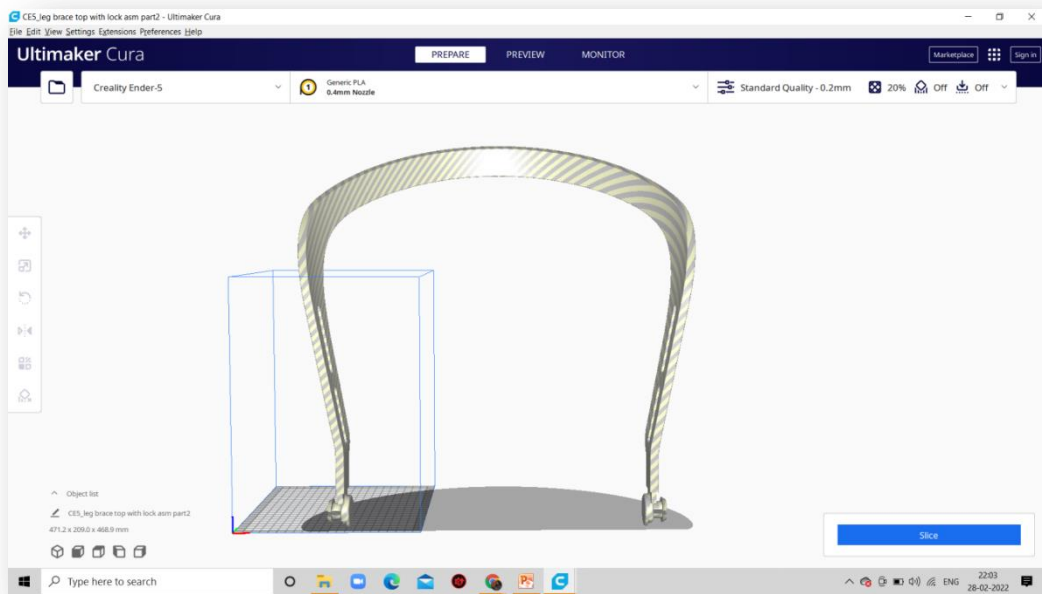


Fig: 4.4: Back view of our prototype in Cura software

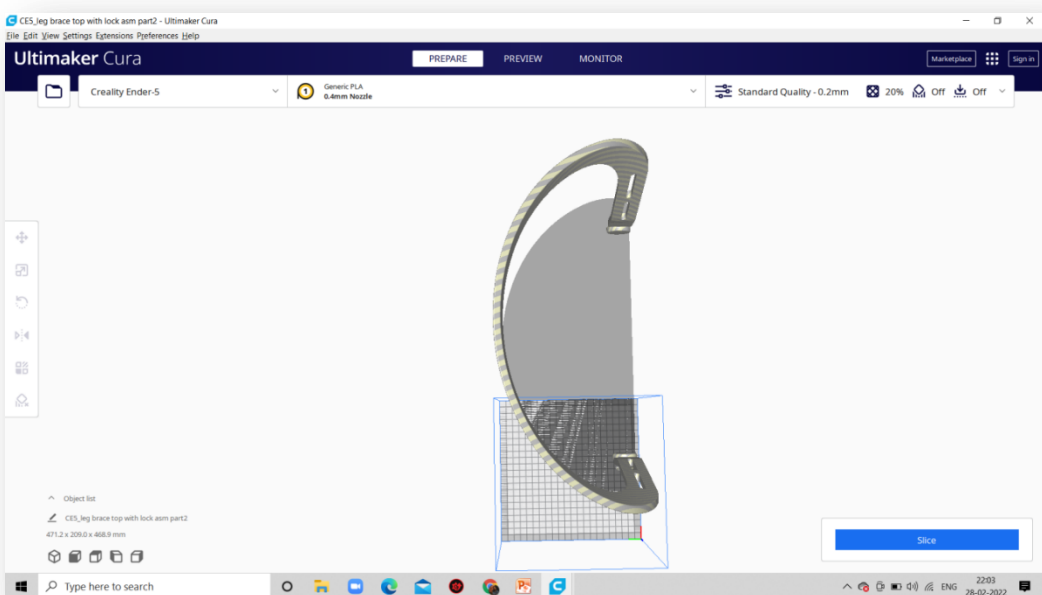


Fig: 4.5: Top view of our prototype in Cura software

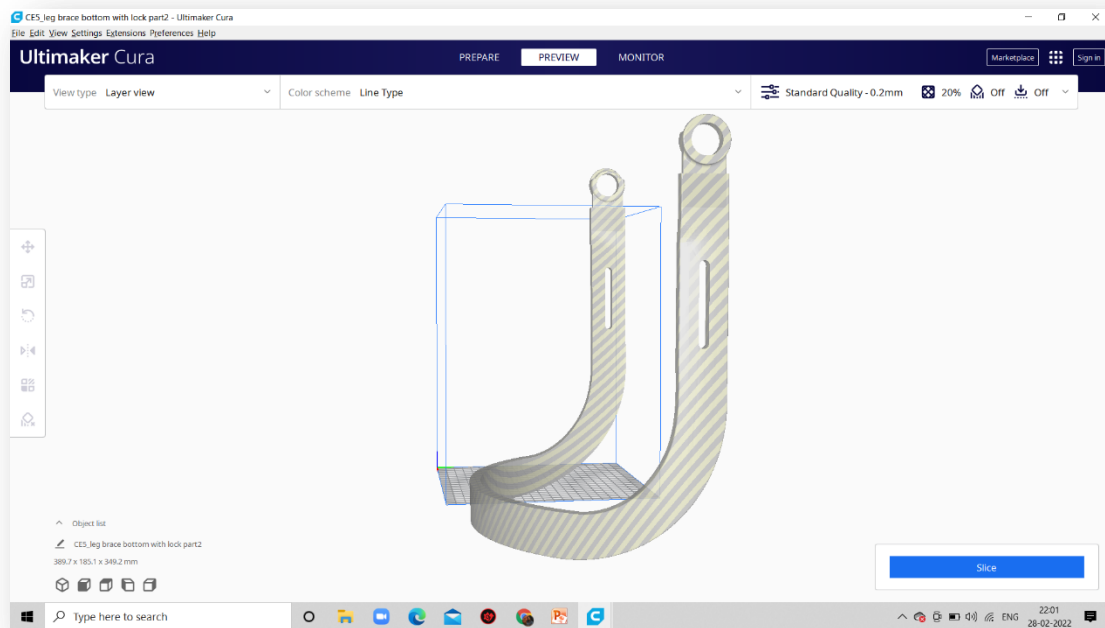


Fig: 4.6: Side view of our prototype in Cura software

The above slides are our own designed knee brace model. The knee brace model is designed using Rhino software. Then it is opened with Cura software for slicing purpose. The front, side, bottom and top view of our knee brace model is viewed under the Cura software.

CHAPTER 5

RESULTS & DISCUSSIONS

The following results are stimulated under the ANSYS software.

1. Stress
2. Strain
3. Displacement

ANSYS is software that can solve a wide variety of numerical mechanical real world problems. The problems include are static/dynamic, heat transfer, fluid basis, structural analysis, electromagnetic problems (K.Anirudh Shivraj Narayan Yeole, 2021).

5.1 STRESS

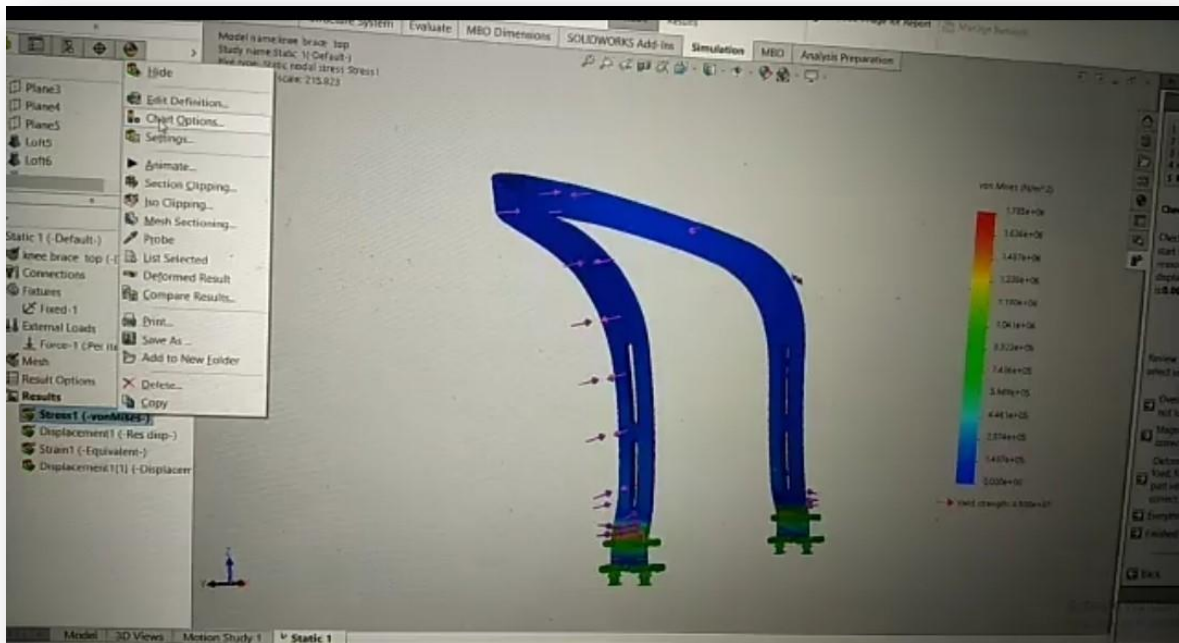


Fig: 5.1: Stress test stimulation in ANSYS software

It is a response to a physical condition. It is a state of body overcomes a demanding or undesirable situation. The stress includes the involvement of both nervous and endocrine system. A factor that causes stress is stressors. Here our prototype is exposed to stressor which is software stimulated, it is elicited to overcome it. The stress Stimulation result is shown in Fig 5.1.

5.2 STRAIN

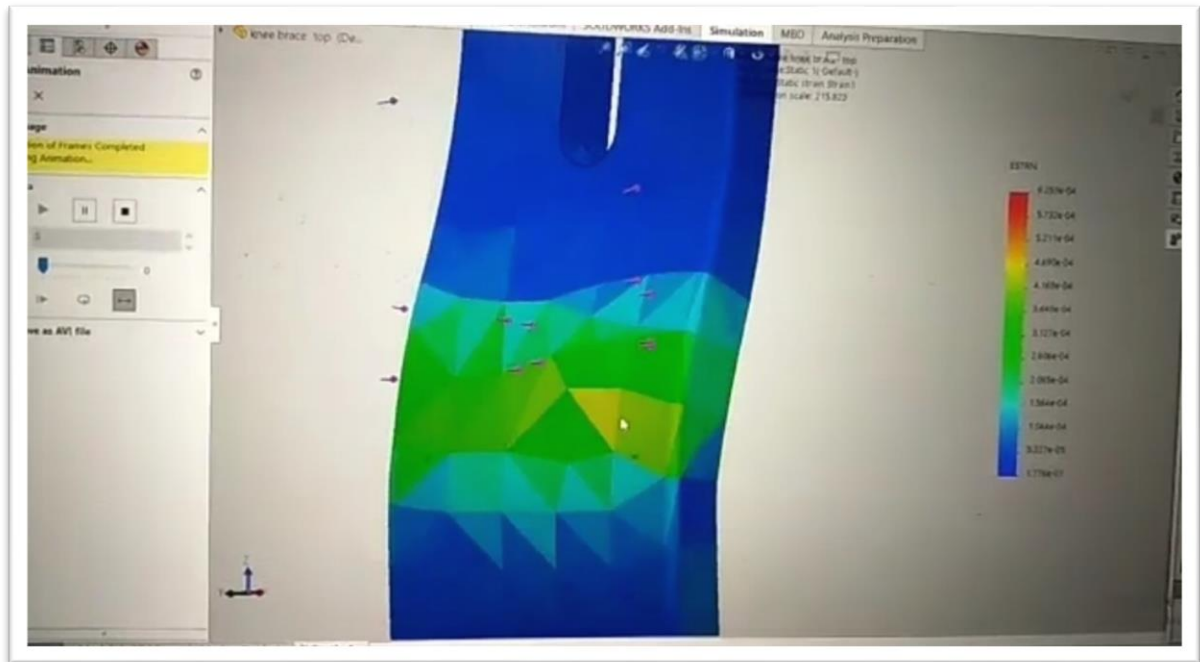


Fig: 5.2: Strain test stimulation in ANSYS software

It is the change produced in response to the stress. It can be classified in to two major types. They are elastic strain and plastic strain. The elastic strain is in which it is completely reversible up to certain point of stress. The second type is plastic strain in which it is partially reversible or completely irreversible up to a certain amount of stress. Here the prototype model, experience a certain amount of strain, and it is reversed to its original state. The Strain test stimulation test is shown in Fig 5.2.

5.3 DISPLACEMENT

The amount of distance in which our prototype model can be stretched is termed as displacement. It is not same as deformation. Deformation refers to bending twisting and stretching behaviour of object whereas displacement is referred as rigid body displacement, where the object moves but does not stretch or deform at any circumstance. Using the software the top and the bottom ends of our prototype design is forced up to a distance that it can withstand. It can withstand upto certain level of breakage point. It makes the users to freely remove and lock our knee brace model without any restrictions. Also it sounds the elasticity of the prototype model. This so-called displacement force test gives an overview of how prototype model behaves. The initialization of displacement test is shown in Fig 5.3.

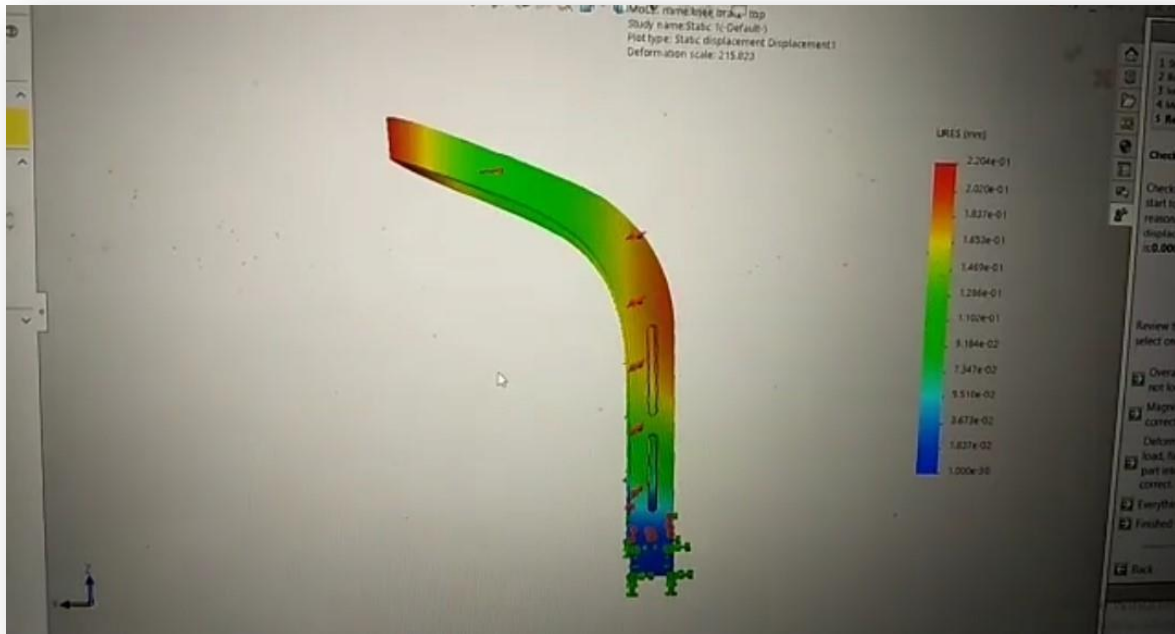


Fig: 5.3: Displacement test stimulation in ANSYS software

As the knee brace is used for the static and dynamic impact force it must be analysed and simulated for different force/pressure. From BS EN-1621 standards the knee brace is tested and simulated at 27N. the modelling knee brace is simulated for different speed based on static and dynamic applications. The ranges of the force/pressure is from 0N to 27N. the knee brace is tested for 27N force acting on the internal surface and with different impact velocities. The displacement test is shown in Fig 5.4.

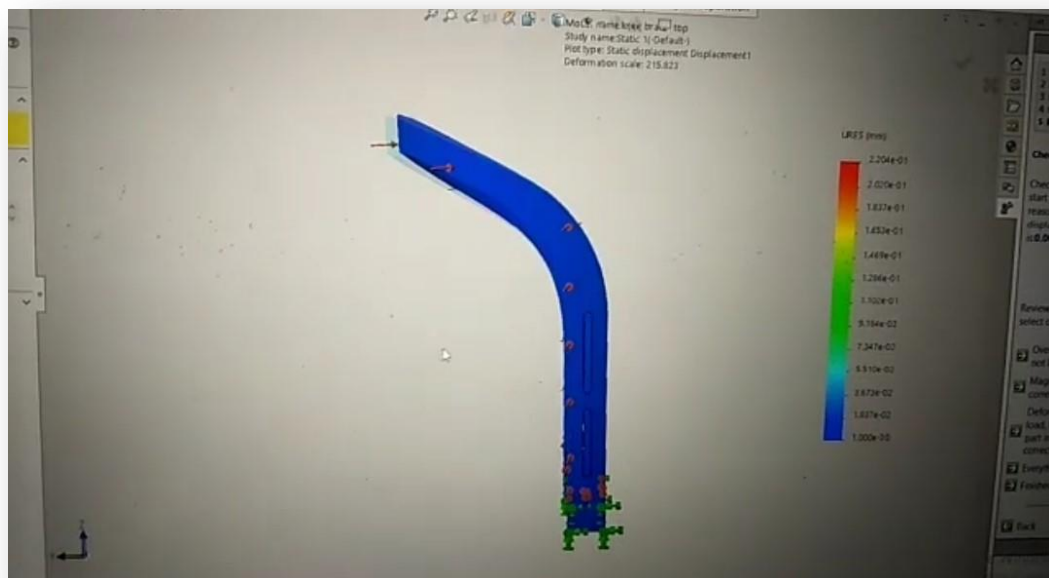


Fig: 5.4 : Displacement test stimulation in ANSYS software

5.4 CALCULATION

- The values are ranging from minimum 0 N to maximum 27 N.

$$1 \text{ kg} = 9.8 \text{ N}$$

$$3.0 \text{ kg} = 29.4 \text{ N (Rat)}$$

- We took the value which is equivalent to 27 N.
- The animal model testing is done.
- From the stimulated results we can conclude that the above mentioned stress, strain, displacement test values are ranging between 0 N to 27 N.

5.5 PROTOTYPE MODEL

The Fig 5.5 and Fig 5.6 are our prototype



Fig: 5.5 Prototype model Side view



Fig: 5.6: *Prototype model Back view*

CHAPTER 6

SUMMARY AND CONCLUSIONS

The most common injuries in sports occur at joints and head. The concurrency of the knee injury is 20%-30%, the customized knee brace is modelled by using patient data. Nylon, PLA, PETG materials exhibited less deformation. Based on the equivalent stress, strain and displacement analysis it is observed that ASA knee brace has good strength properties. Therefore, ASA material sustains more load when compare to other materials. As mentioned above that knee braces can be designed using various materials like Nylon, PEEK (Polyether Ether ketone), PLA, PETG (polyethylene terephthalate glycol), ABS (Acrylonitrile Butadiene Styrene), ASA (Acetyl salicyclic Acid), and ULTOM. Our method of design using ASA material exhibits excellent property of strength and durability. In addition, our product is 3D customized printed knee braces, which creates greater boom in upcoming days. Hence the modelled knee brace can be used for the ACL reconstruction patients for protecting the knee.

References

1. Anirudh Shivraj Narayan Yeole K “Development of a 3D printed knee protective pad prototype” 2021.
2. Deepa Beeta Thiya “Customized Knee Brace for Osteoarthritis Patient Using 3D Printing A Customized Knee Brace Using 3D Printing : A Customized Knee Brace Using 3D Printing 2021
3. Gayathry V “Customized Knee Brace for Osteoarthritis Patient Using 3D Printing A Customized Knee Brace Using 3D Printing : A Customized Knee Brace Using 3D Printing” 2021
4. Jim C “Customized Knee Brace for Osteoarthritis Patient Using 3D Printing A Customized Knee Brace Using 3D Printing : A Customized Knee Brace Using 3D Printing” Elliot 2021
5. Kay M.Crossley David C.Ackland Natalie J.Collins. “Effects of an unloader knee brace on knee-related symptoms and function in people with post-traumatic knee osteoarthritis after anterior cruciate ligament reconstruction”, 2015
6. Linda R Swirtun, Anna Jansson, Per Renström. “The effects of a functional knee brace during early treatment of patients with a nonoperated acute anterior cruciate ligament tear: a prospective randomized study” ,2005
7. Muhammad Hanif Ismail & Mohammed Najib Salleh “Computer-aided knee braces fabrication” Breg 360 customer care. (2016). Retrieved from knee braces: <http://www.breg.com/products/knee-bracing>. FamilyDoctor.org. (2016)
8. Sanders T L, Maradit Kremers H, Bryan A J, Larson D R, D, Dahm D L, Levy B A, Ageberg E, Dunn W R, Spindler K P. “The effect of proprioceptive knee bracing on knee stability after anterior cruciate ligament reconstruction”
9. Stephen W Hutchins, Monireh A Bani, Sarah Curran, Andrey Aksenov. “The influence of a bespoke unloader knee brace on gait in medial compartment osteoarthritis: A pilot study”, 2014
10. Trevor B. Birmingham ,Dianne M. Bryant , J. Robert Giffin. “A Randomized Controlled Trial Comparing the Effectiveness of Functional Knee Brace and

Neoprene Sleeve Use after Anterior Cruciate Ligament Reconstruction”
,2008

11. Wilson B, Rankin H, Barnes CL. “Long-term Results of an Unloader Brace in Patients With Unicompartmental Knee Osteoarthritis” ,2011