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Fabrication of Prosthetic Robot Finger

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Abstract:- In this paper, we will examine the design and fabrication of a prosthetic robotic finger using Polylactic Acid (PLA) and a modern 3D printing technique. The finger will be controlled by small motors, involving a driver, battery, and microcontroller for 3D modules. The design provides for an artificial finger controlled by soft robotics which is designed to assist people who have lost fingers in an accident. In conclusion, there exists an artificial finger that aims to mimic movement and function just like a human finger.

Keywords:- *Prosthetic, Robot Finger, PLA, Flex Sensor, Arduino, 3D Printing, Servo Motor.*

I. INTRODUCTION

The designing and fabrication of a robotic finger using a prosthetic approach through the low-cost technique of 3D printing technology that encompasses bootstrap customization. PLA was chosen because of its biocompatibility, ease of use, and environmental friendliness during the exceptional fabrication of rapid prototypes for prosthetic devices. The design strives to create a prosthetic finger that translates natural finger motions faithfully while being lightweight and convenient for prolonged use. The design features joint articulation patterns that mimic natural finger motions to facilitate the most elementary tasks of holding and pointing. Component assembly is achieved with nylon thread, which gives the flexibility and strength for it to articulate smoothly. Being lightweight and biocompatible allows the material to be used in those parts of the prosthetic that do not carry weight, assuring comfort during use. Although PLA is great for prototyping, it suffers certain limitations such as brittleness and lack of heat strength that stop it from being applied in high-stress applications. The 3D printing shows how different solutions can be of low cost yet functional and quite tailored towards the users. The new approach allows prosthetic devices to produce custom orders in an economical way, thus making them accessible to those who need them. Finally, it shows how additive manufacturing can develop low-cost and working solutions for prosthetics in a customized way to suit the diverse needs of all kinds of users.

II. METHODOLOGY

A. Requirement Analysis

The first phase of the project was to find the problem (to be solved) and analyze the particular needs of the prosthetic users. The core aim is to create a prosthetic robot finger to offer functionality similar to a natural human finger, focusing on flexibility and grip strength and ease of use. Requirements using range of motion, finger dexterity, weight, durability, and cost were targeted with engaging potential users and reviewing existing prosthetic designs.

B. Design Development

As per the requirement analysis, the design process that started at first was followed up with making conceptual sketches and then producing a detailed design using CAD software. The prosthetic finger design was aimed at imitating the natural movement of the finger.

- Mechanical Design: Distinction was made among the three segments of the finger: phalanges, joints, and mechanisms of actuation. The design considered rigid components for structural integrity in combination with flexible joints acting on motion. Movement of the finger, the configuration of its different segments, was made to be either through servo motor, thus granting smooth motion following natural motion.
- Simulation: The CAD models were used to simulate the action of the finger to ensure enough swing from the dimensions and engage one another.

C. Material Selection

Prosthetics were made of PLA (Polylactic acid) as their main material. Due to PLA being a widely used thermoplastic and biodegradable, originating from renewable resources like cornstarch or sugarcane, it is gaining prominence in 3D printing because of its ease of use and biocompatibility. PLA offers excellent properties in terms of lightweight and customizability of the prosthetic fingers.

- Sensors: The flex sensors can be used to give fingertip position or pressure feedback for refined control.
- Motors: A small servo motor or an actuator (i.e. linear actuator or pneumatic muscle) will be used to actuate the finger joints. The actuator must be chosen according to various parameters, including size, torque, and power efficiency.
- Nylon string: Nylon thread is commonly used in prosthetic robot finger assembly.
- Electrical components: Microcontrollers like Arduino for controlling servo motors and processing sensor data.

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D. 3D Printing

Once the design in CAD is completed, it will be exported as an STL file. The 3D printer settings-such as layer height; infill density; and print speed-are chosen based on material compatibility and the degree of strength desired in the prosthetic finger. Using an FDM (Fused Deposition Modeling) printer, the components of the prosthetic finger will be printed layer by layer.

III. IMPLEMENTATION

A. Designing

Solid works software was used to design the prosthetic finger While anatomy of the human finger provides itself with many static model sources, such as joint architecture and tendon routing, the objective of this project is to create a functionally fully integrated robotic finger system with state-of-the-art engineering advancements applied during the design phase. This section entails the mechanical design and printing of our p-finger as illustrated. The detailed drawing of the robot or prosthetic finger is shown in the below figure 1.

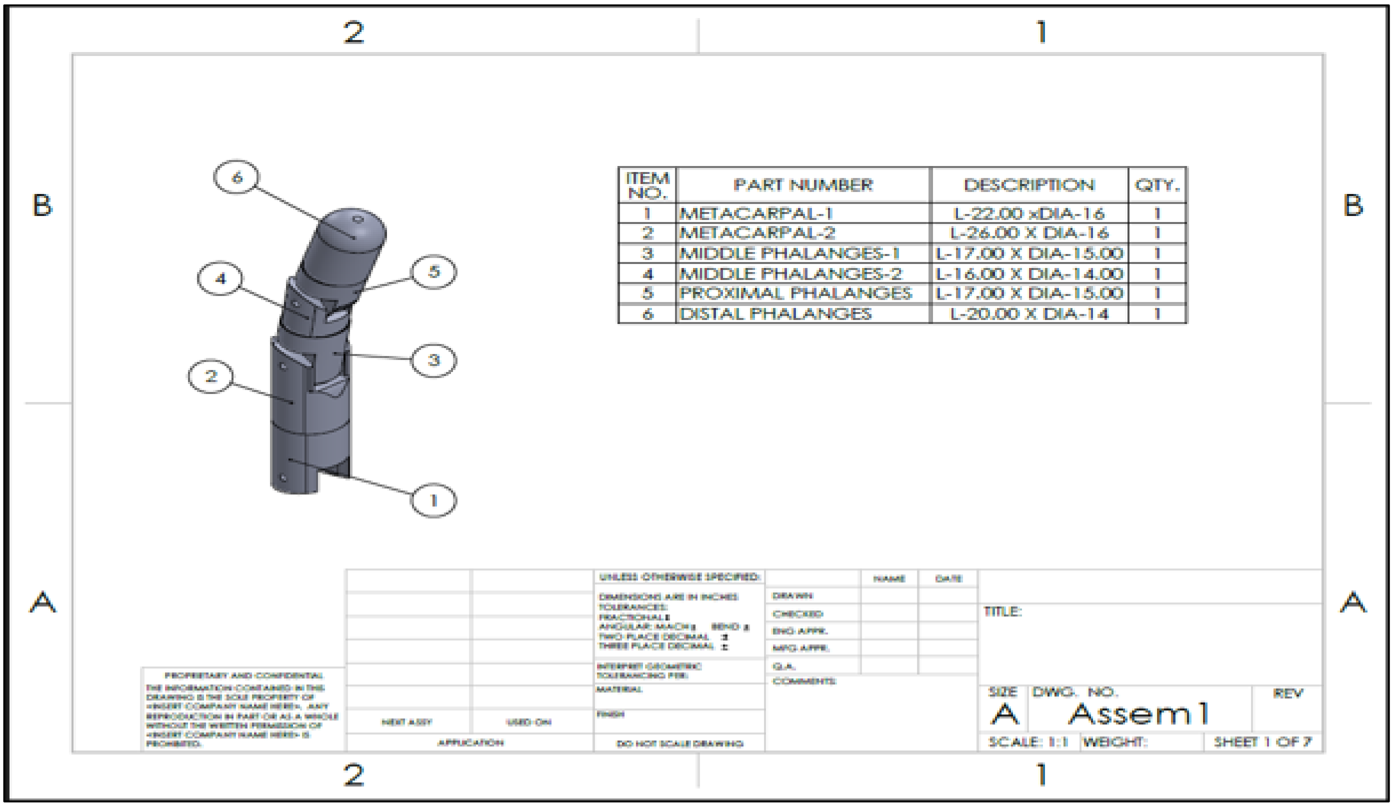

Fig 1: 6 parts of the finger designed in SOLIDWORKS software

Our articulated finger design consists 6 finger parts of one index finger. The dimensions of our prosthetic analog are closely matched to that of the actual finger and its mechanical design made in SOLIDWORKS. The drawings of each individual part of the index finger are shown the below figures.

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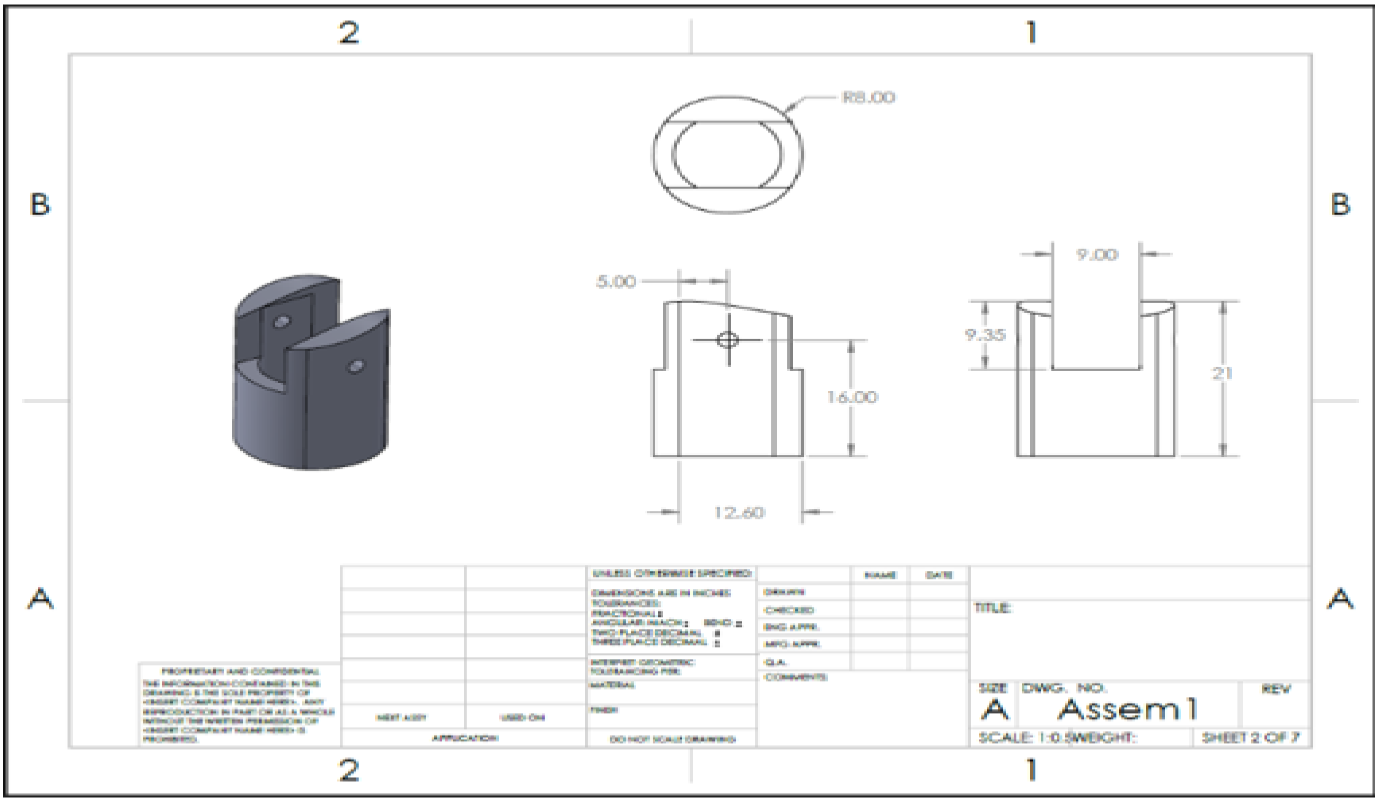

Fig 2: Part 1 of Finger (METACARPAL-1)

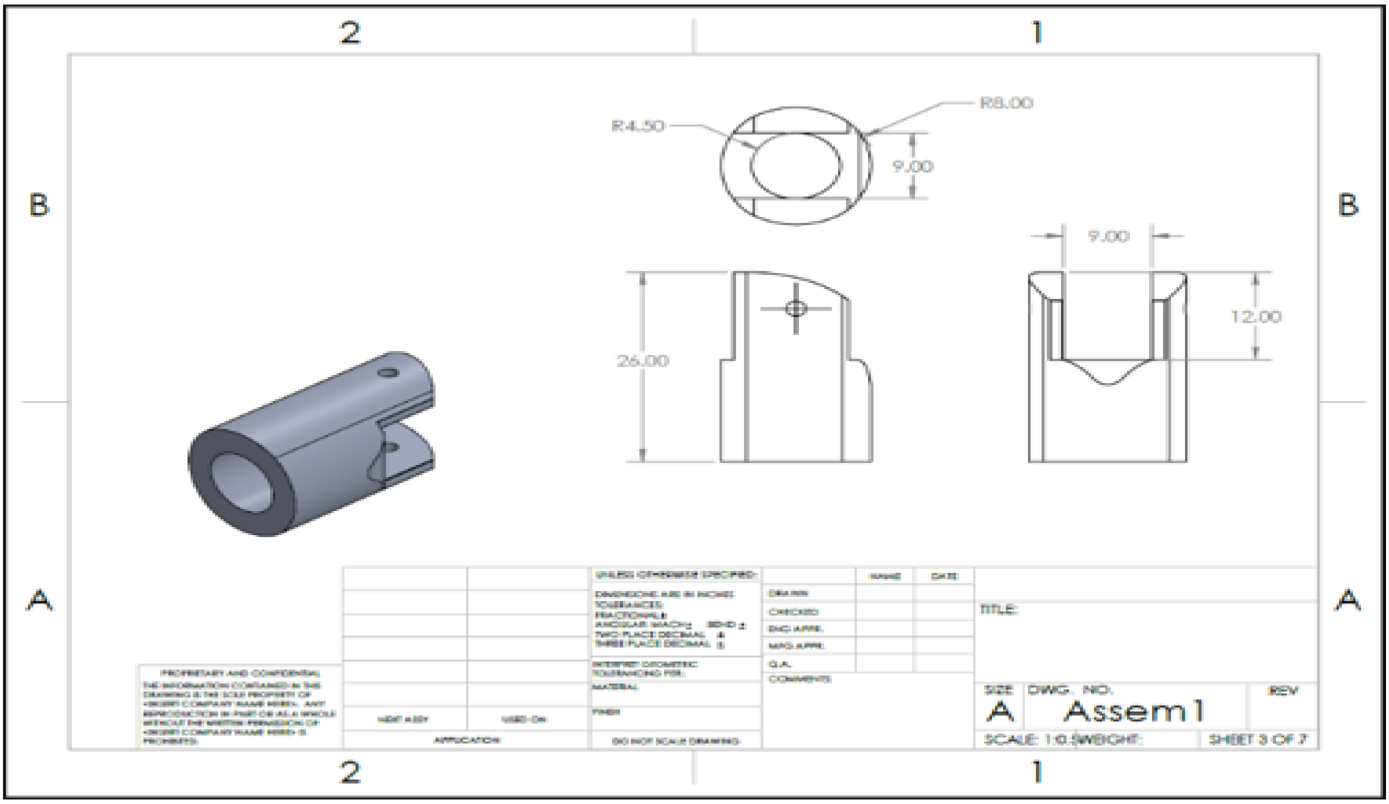

Fig 3: Part 2 (METACARPAL-2)

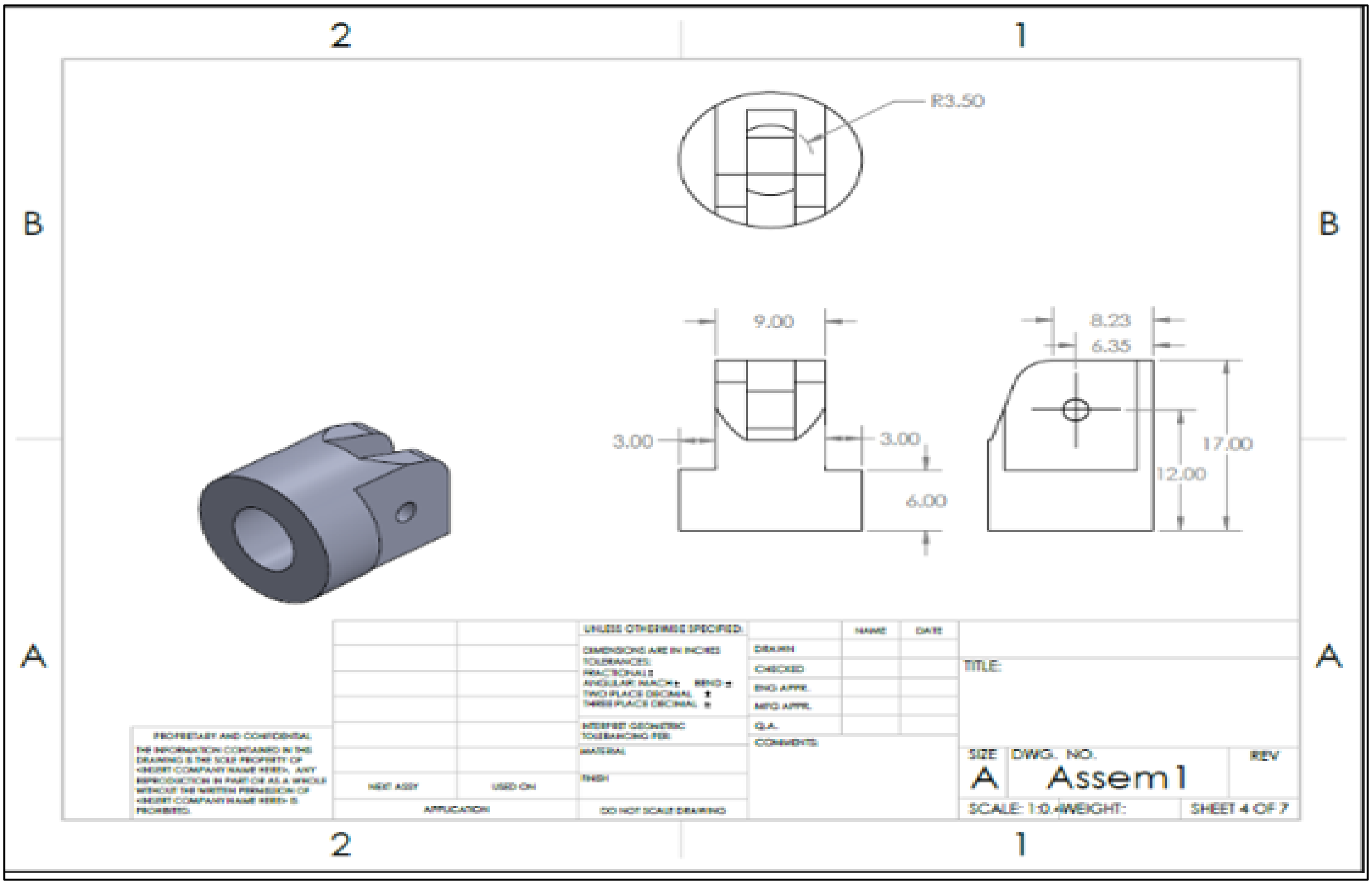

Fig 4: Part 3 of finger

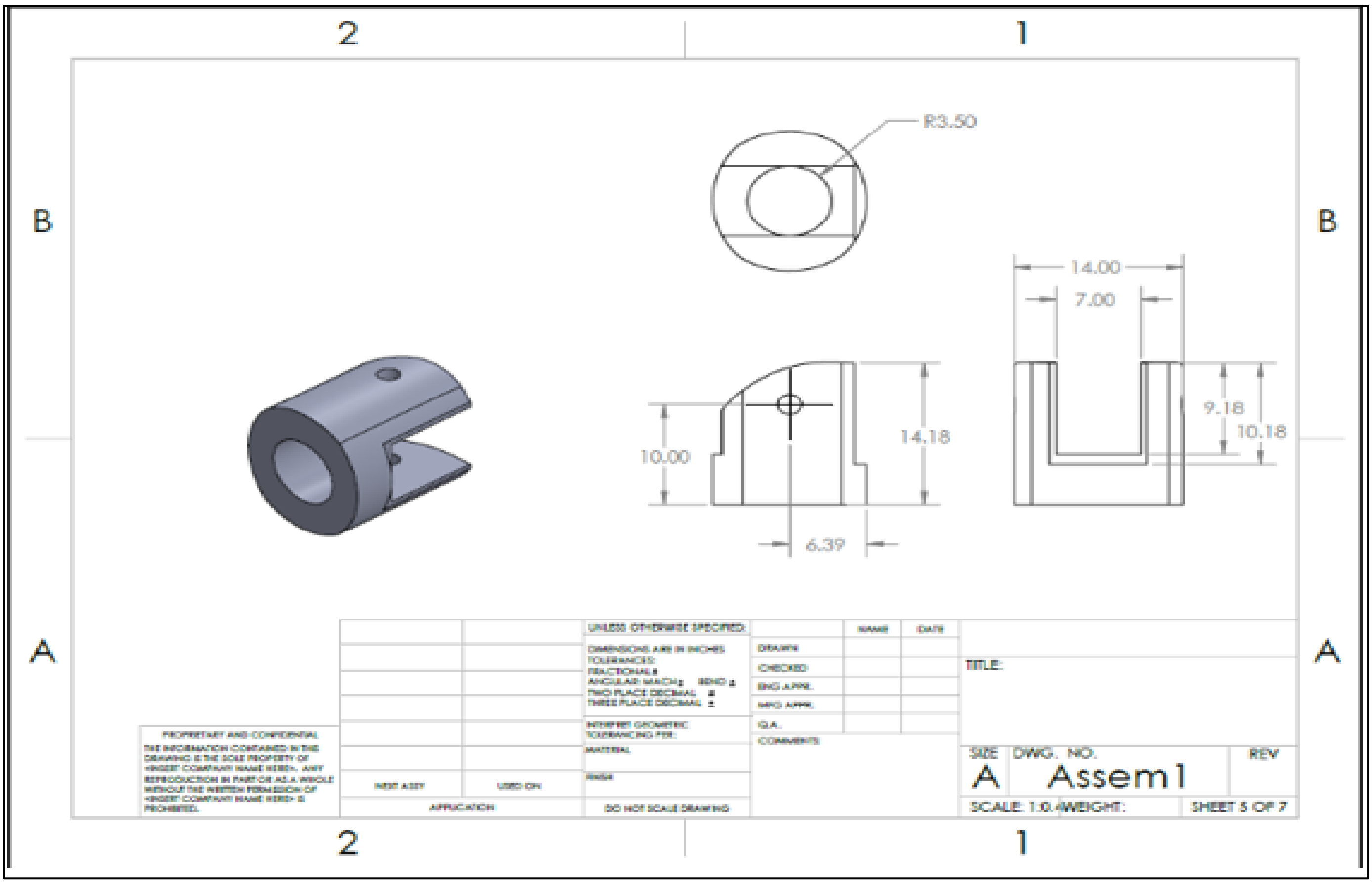

Fig 5: Part 4 of Finger (Middle Phalanges-2) (MIDDLE PHALANGES-1)

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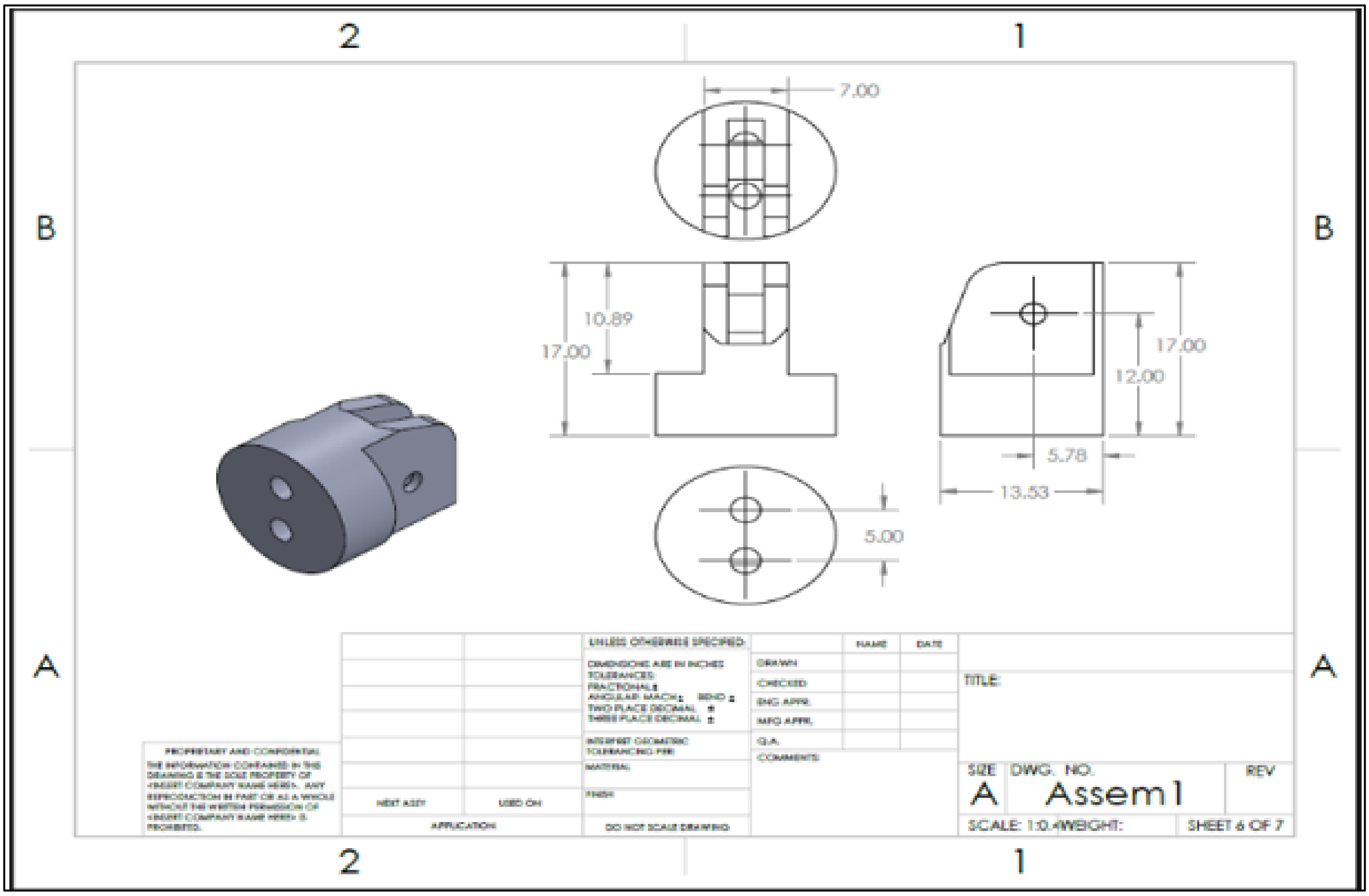

Fig 6: Part 5 of the Finger (Proximal Phalanges)

B. Material Selection

When comparing PLA (Polylactic Acid) and ABS (Acrylonitrile Butadiene Styrene) as prosthetic robot finger design and fabrication materials, they have advantages and drawbacks. PLA, on the other hand, was selected because it's easier to work with, biologically compatible, and inexpensive, thus making it a great option for prototypes of such non-load-bearing parts. It is a very popular material due to the very easy 3D printing properties, active temperature window (190-220 C), and little to no warping compared to ABS. PLA would not be an appropriate material to use for prosthetics worn in hot conditions. However, ABS struggled to require more demanding printing conditions and post-process methods, like acetone smoothing, thus making fabrication difficult.

Table 1: Material Properties of PLA

SNO	MATERIAL PROPERTIES	PERCENTAGE %
1	Tensile strength	50-70 MPa
2	Flexural modulus	2-3 GPa
3	Heat resistance	Low: around 60°C, Melting temp: approximately 150-160°C
4	It exhibits minimal shrinkage during cooling. (It leads to dimensional accuracy in 3D printing.)	N/A
5	Ease of processing	N/A
6	Biodegradability	N/A

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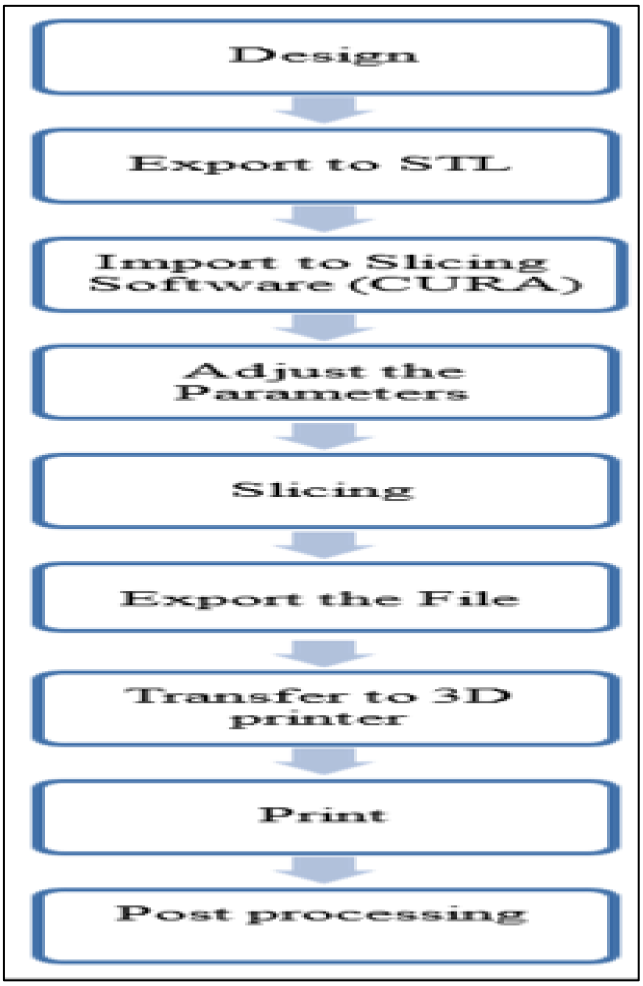
C. 3D Printing

The prosthetic components such as phalanges, joints are printed one layer at a time, from the top to the bottom. Depending on the design and the size of each component in a prosthesis, this can take a few hours to a day. Since the 3D printer supports the STL format, any design should be converted into STL format to fabricate the design. PLA wire (poly lactic acid wire) is the input material given to printer. And the process of approach for 3d printing is shown in below flow chart.

- Post-Processing: Once printing is finished, any support structures are removed with care, and the parts are cleaned to create a smooth finish. The parts that are printed together are aligned for fitting purposes to check for the alignment of the joints so that they may work.



Flow Chart 1: Process of Approach

D. Assembly of the Parts:

The assembling 3D printed parts with nylon thread the simplest and most effective way to create flexible joints and fix components that demand mobility-such as those used for prosthetic robot fingers. The nylon thread generally connects parts like finger segments or joints through holes or eyelets for movement and flexibility. The 3D printed parts, such as the finger segments, are first printed with specific holes or eyelets at the joint positions to allow the nylon thread to be passed through. These holes need to be properly aligned so that the movement and flexibility can be achieved. Once threaded, the ends are knotted together with enough tension so they serve to restrict any considerable movement but still provide inner slack so that the parts move freely. This method is commonly adapted in making articulated joints for prosthetic fingers since nylon affords a smooth connection that is flexible and also has none of the rigidity associated with other conventional fasteners. In some cases, these knots can be reinforced by a small drop of glue, which serves to assure that the knots remain tight and do not loosen over time. The assembled joint is finally subjected to testing to ensure that its movements and durability meet the expected.

E. Integration of Actuators and Electronics

Attaching the servo motors: The servo motor, situated where the metacarpal region meets the first joint at the base of the prosthetic finger, provides for flexion/extension through tendons or strings that pass through small holes in the phalanges. It is mounted inside the PLA casing to make sure it remains stable during operation and no alignment is disturbed. Arduino Nano: A microcontroller that is used to control the servo motors relying on input from either the user or sensors. Arduino reads the input from either the flex sensor and controls the servo motors to simulate finger movements. Wiring: This includes proper wiring to connect the servos and the sensors to the Arduino board. It makes sure that the wires are well routed through the prosthetic housing, thus being a compact assembly. Power supply: It should be between 9V and 12V DC.

F. Software and Control System

The Arduino code for the servo and flex sensor:

```
#include <Servo.h>
Servo fingerServo;
int flexSensorPin = A0;
int sensorValue = 0;
int servoPos = 0;
void setup() {
  fingerServo.attach(9);  // Attach servo to pin 9
}
void loop() {
  sensorValue = analogRead(flexSensorPin);
  servoPos = map(sensorValue, 0, 1023, 0, 180);  // Map sensor value to servo position
  fingerServo.write(servoPos);
  delay(15);  // Wait for the servo to reach the position
}
```

G. Testing and Evaluation

A possible further analysis could combine Finite Element Analysis (FEA) with simulation skills to calculate the displacements and stress distributions in the parts of the finger. This would be achieved through the following:

- Defining the geometry of each phalanx, joint, and tendon.
- Setting the boundary conditions for flexion and actuator forces.
- Solving displacements and stresses at each part of the simulation using specialized FEA software (i.e. ANSYS)

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This technique often gives more accurate and more reliable predictions for complex geometries or when the material properties are required beyond simple displacement formulae. And the following ANSYS results are shown in the analysis section.

IV. RESULT

A. Analysis

The robot finger analysis in ANSYS typically involves simulating the mechanical behavior and performance of a robotic finger under various conditions. This can include tasks like stress analysis, displacement analysis, motion simulation, and material behavior study to ensure the finger functions as intended in its specific robotic application. The analysis of the robot finger parts is done individually for each part. The displacement analysis for the part 1 and part 2 of the finger shown in the below figure 7 and 8.

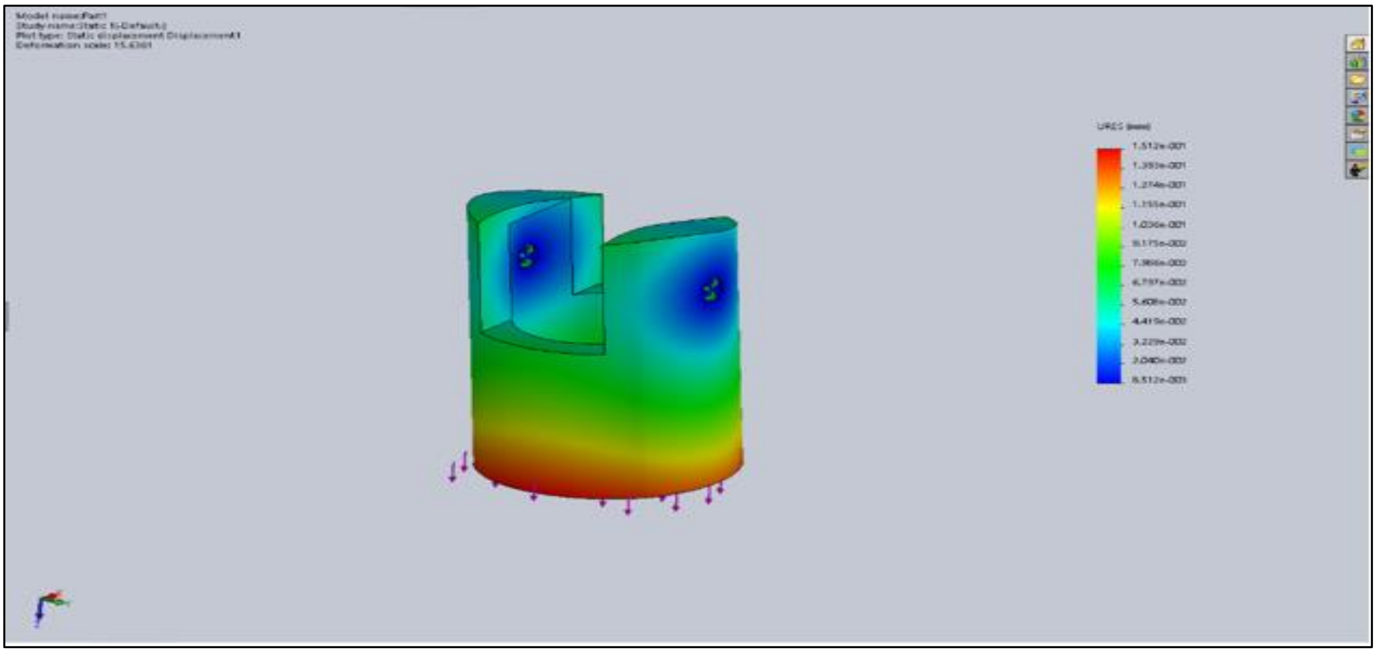

Fig 7: The Displacement Analysis of Part 1 of the Robot Finger

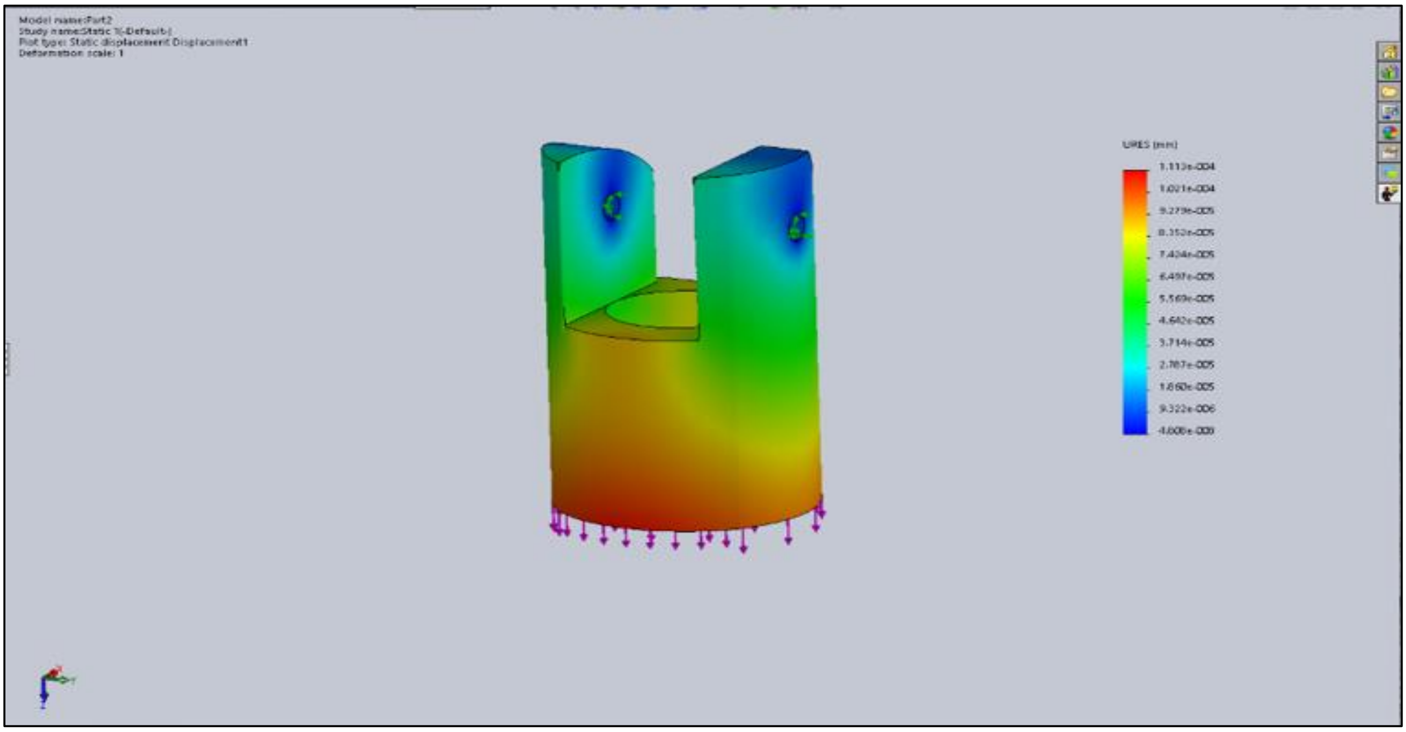

Fig 8: The Displacement Analysis of Part 2 of the Robot Finger

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The displacement analysis was successfully conducted for individual parts of a finger as shown in Fig 9.

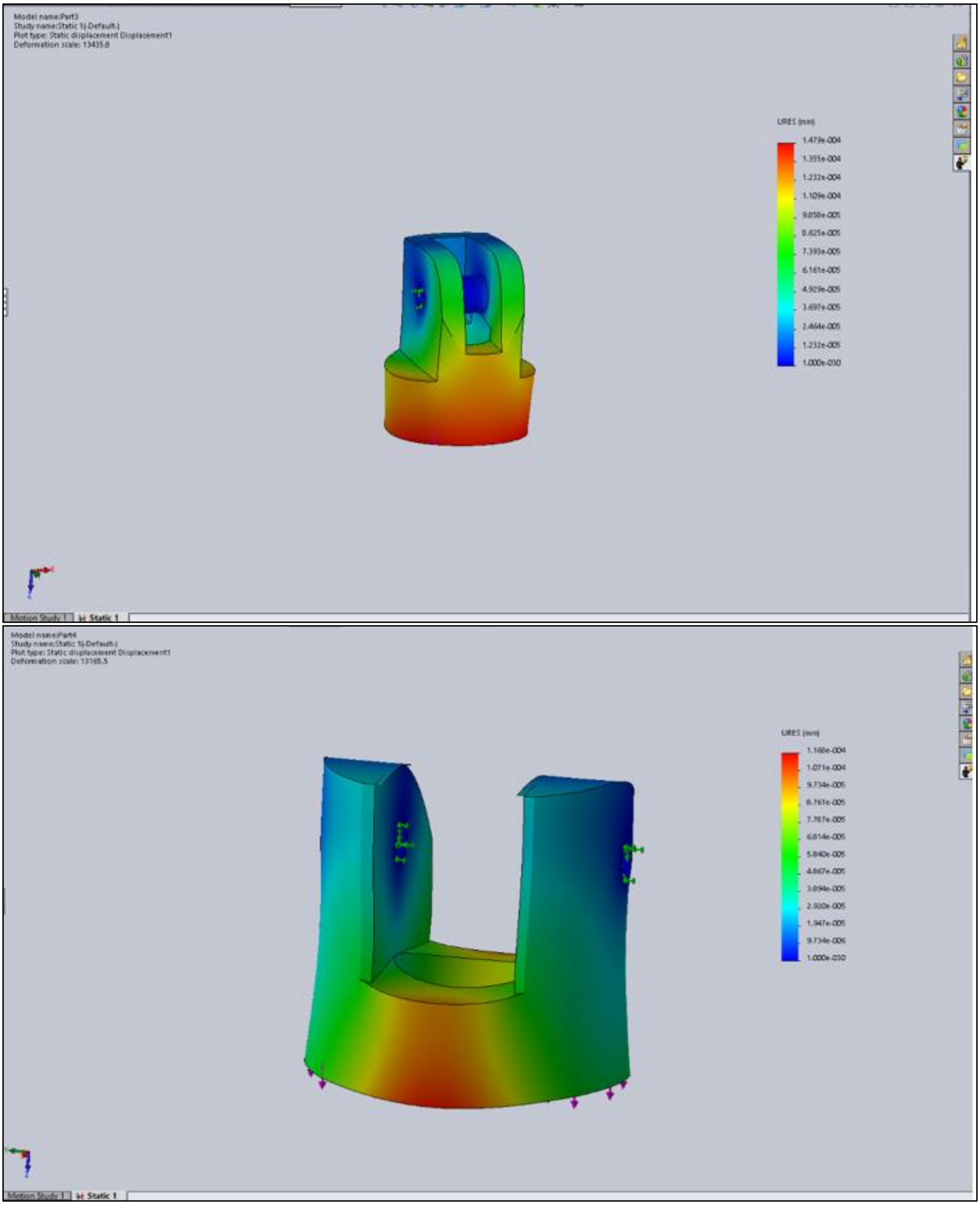

Fig 9: The displacement analysis of part 3 and part 4 of the robot finger

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The static stress (von Mises stress) analysis was successfully performed in ANSYS for individual parts of a finger. The static stress analysis for the part 1 and part 2 is shown in the below figure 10.

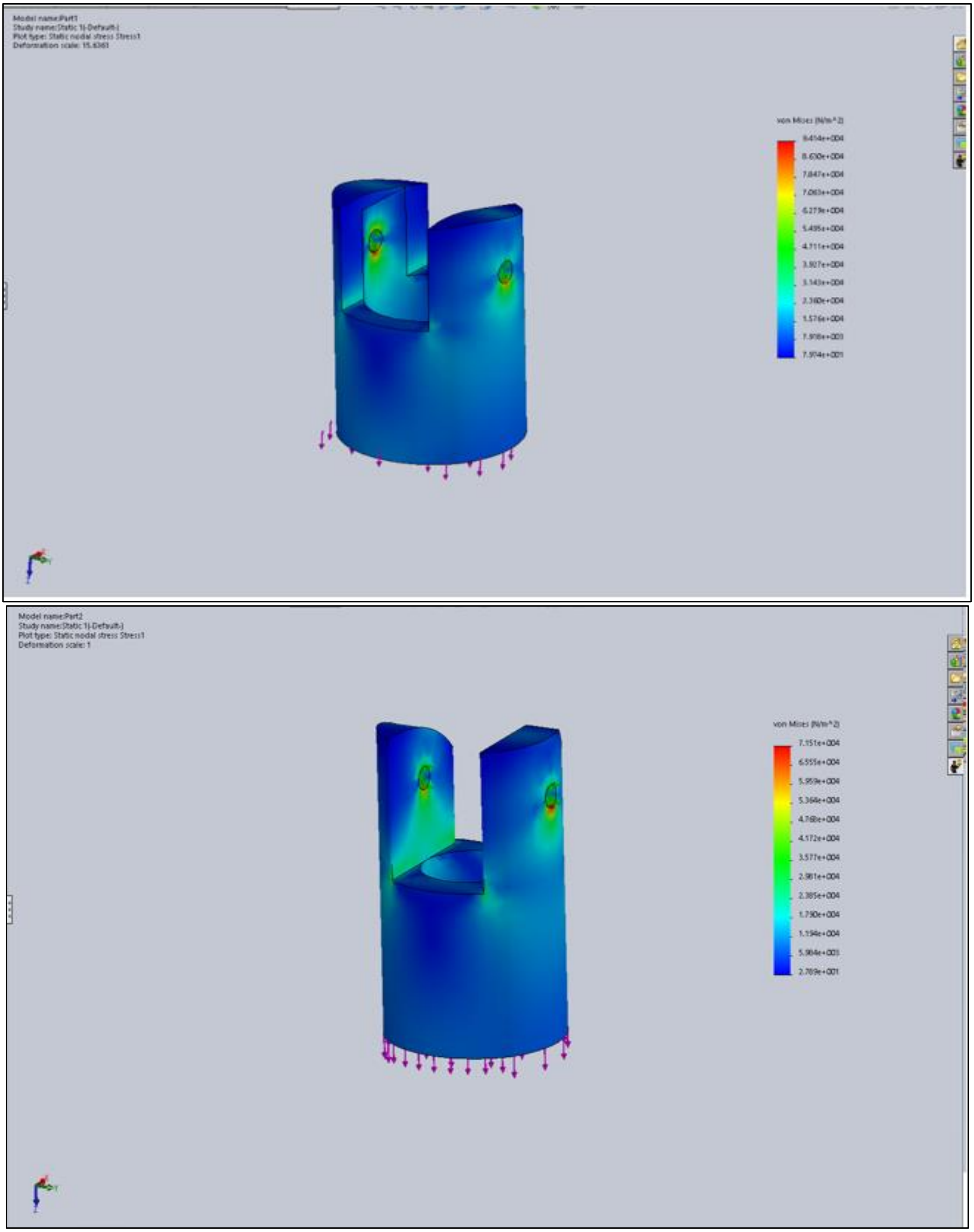

Fig 10: The Static Stress Analysis of Part 1 and Part 2 of the Robot Finger

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The static stress (von Mises stress) analysis was successfully performed in ANSYS for individual parts of a finger. The static stress analysis for the part 3 and part 4 is shown in the below figure 11.

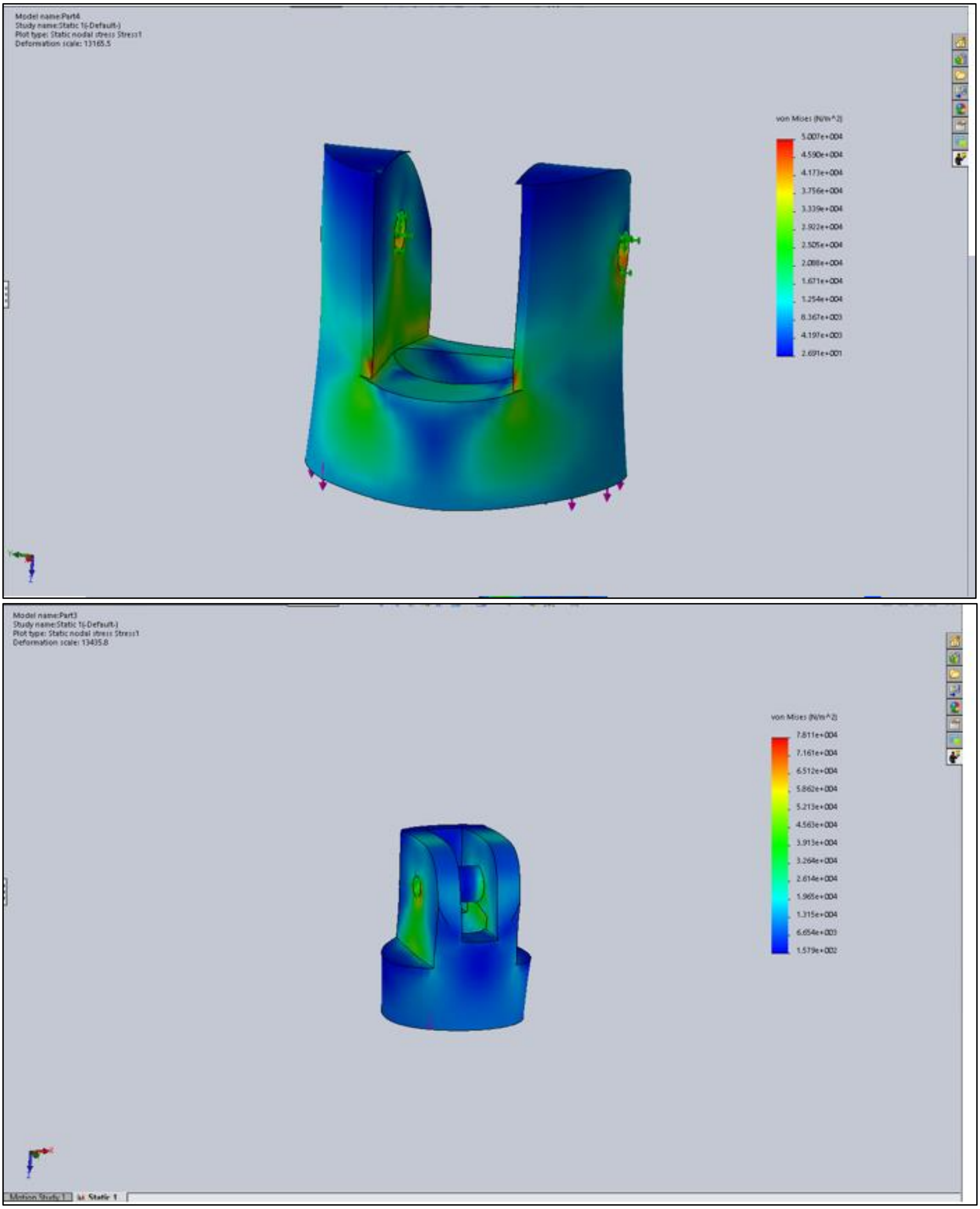

Fig 11: The Static Stress Analysis of Part 3 and Part 4 of the Robot Finger

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The static strain analysis was successfully performed in ANSYS for individual parts of a finger. The static strain analysis for the part 1 and part 2 is shown in the below figure 12.

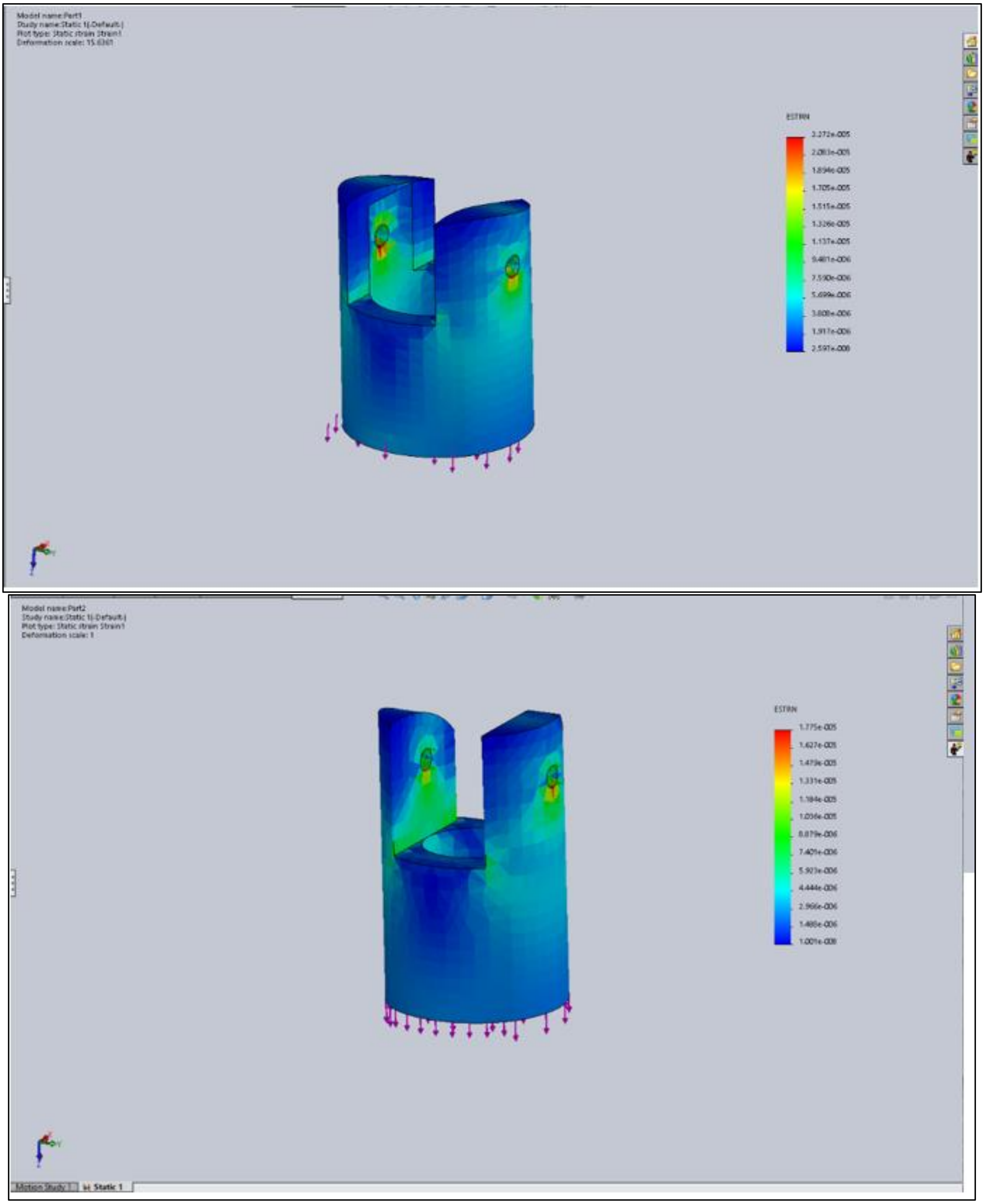

Fig 12: The Static Strain Analysis of Part 1 and Part 2 of the Robot Finger

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The static strain analysis was successfully performed in ANSYS for individual parts of a finger. The static strain analysis for the part 3 and part 4 is shown in the below figure 13.

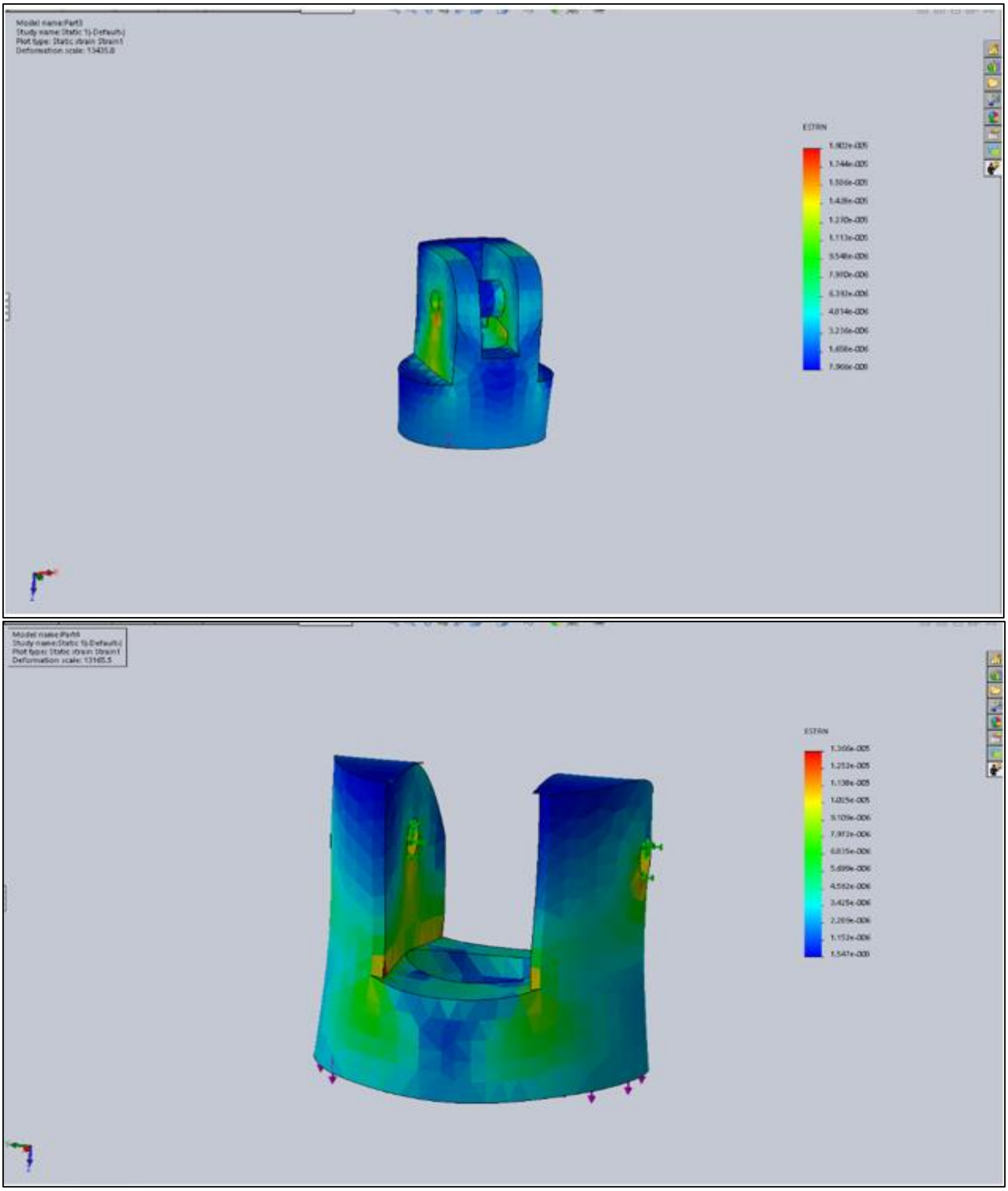

Fig 13: The Static Strain Analysis of Part 3 and Part 4 of the Robot Finger

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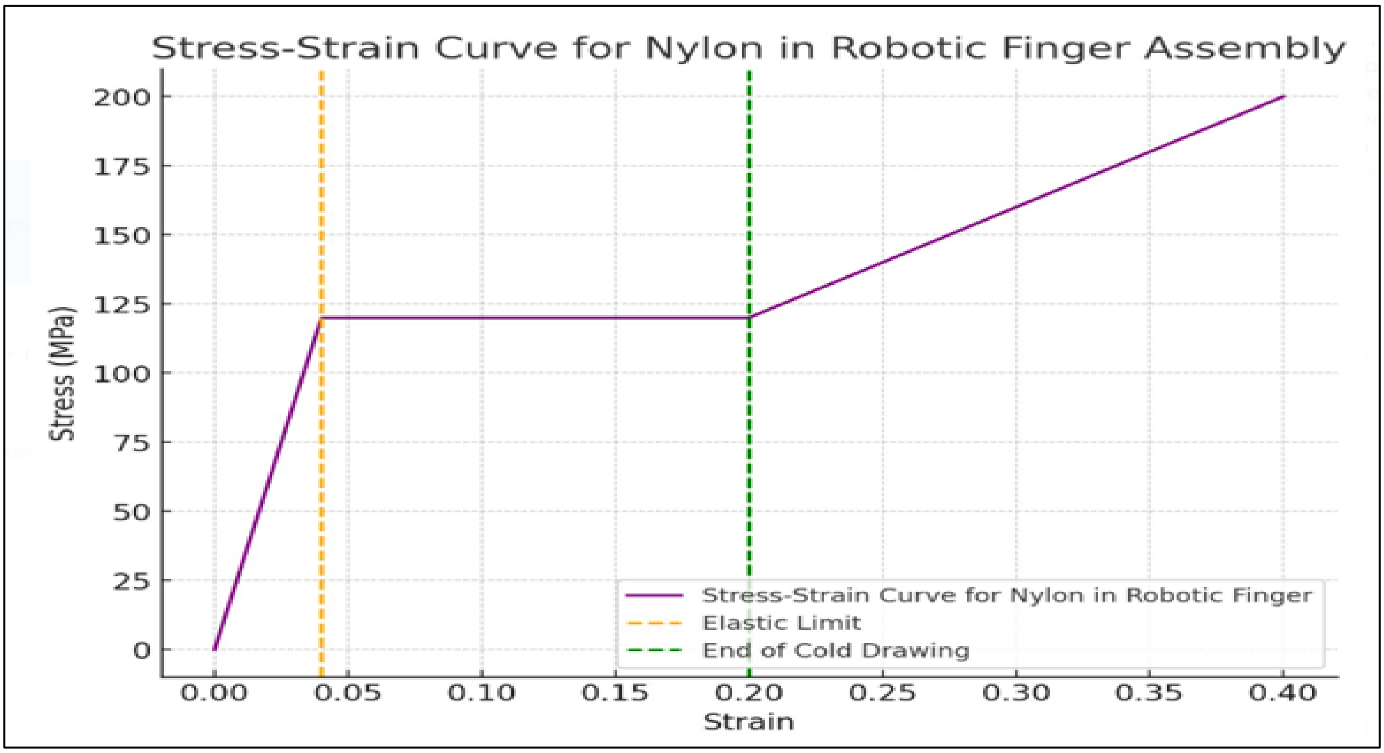
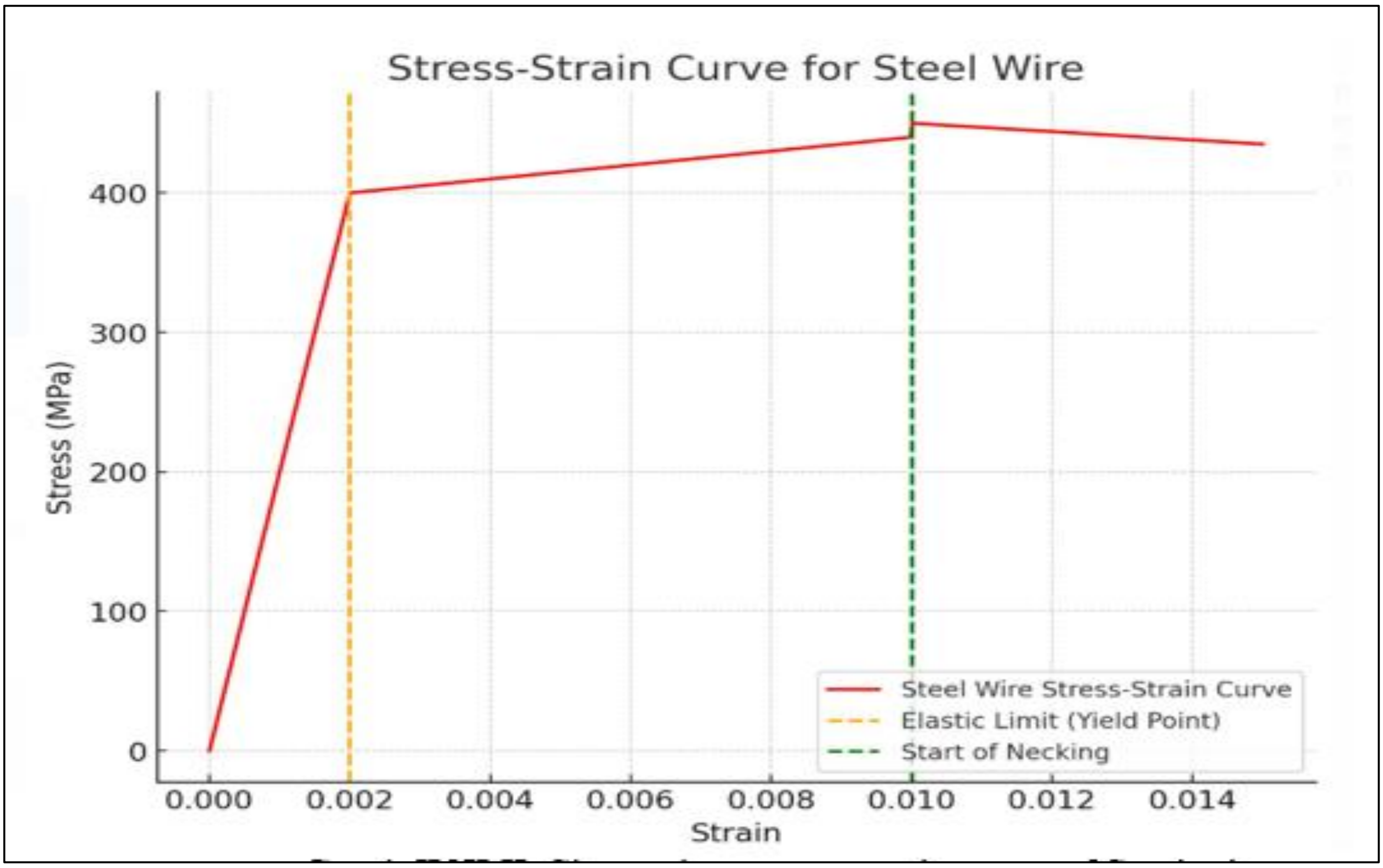
B. Comparison between the Materials Nylon



Graph 1: Shows the Stress – Strain Curve of Nylon Material Steel Wire



Graph 2: Shows the Stress – Strain Curve of Steel Wire

Steel wire is stronger than nylon regarding tensile strength and rejection of breaking. It can carry heavier loads and endure extreme tension for longer than nylon. However, unlike nylon, steel wire is stiffer, so while it may have higher breaking resistance, it is less flexible and more prone to breaking when bent excessively.

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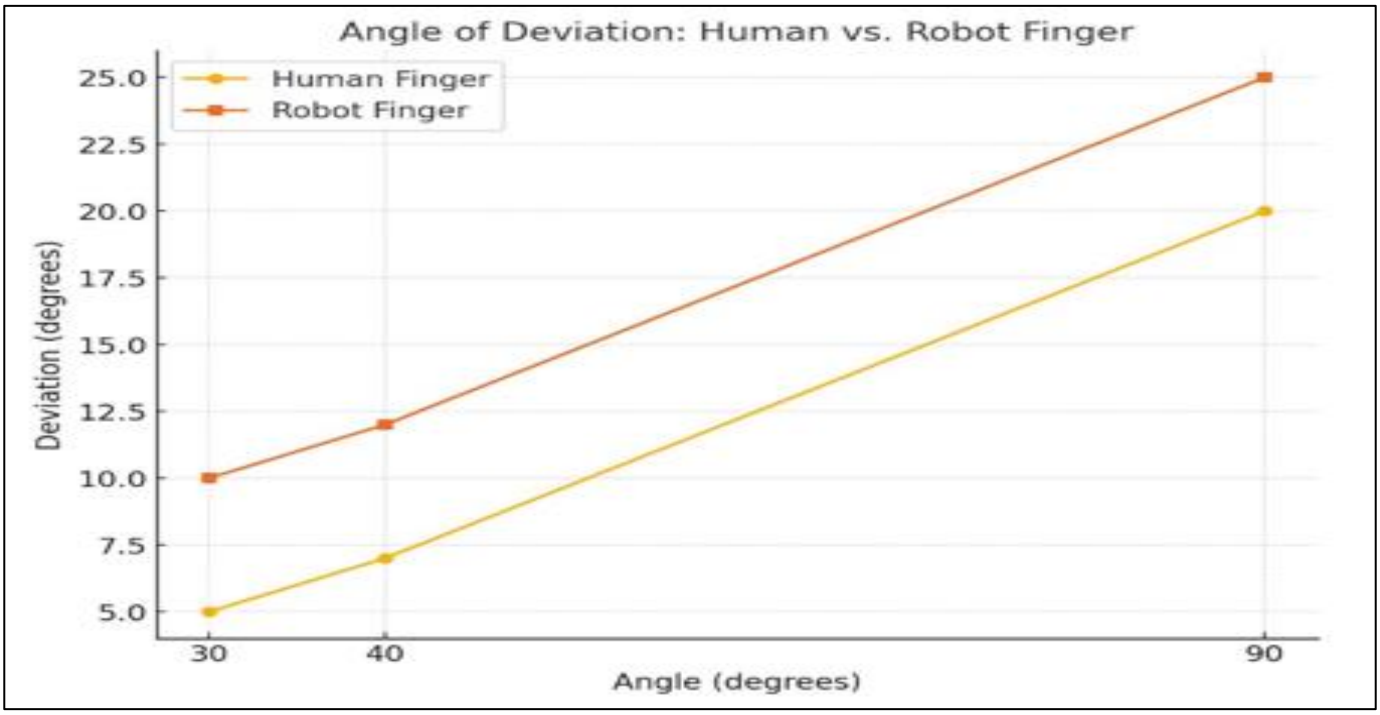
The deviation between human finger vs robot finger is shown in the below graph 3.



Graph 3: Shows the Angle of Deviation between Human vs Robot Finger

V. CONCLUSION

Thus, design and fabrication of an actual prosthetic robot finger using PLA material has turned out to be a successful venture in the producing of a functional, cheap, and customizable solution for prosthetics applications. During the whole phase of this project, we have demonstrated the viability of using 3D printing technology in the production of reasonably realistic and functional prosthetic components, giving an attainable alternative to traditional manufacturing processes. The design of the prosthetic finger is modeled on the anatomy of the normal human hand with several joints designed to actuate motions similar to those of natural fingers, providing considerable flexibility and adaptability.

The use of PLA material provided the right compromise between ease of fabrication, mechanical strength, and cost. Though it is relatively rigid, the finger performs satisfactorily for light-duty tasks, and its biodegradability gives an environmental benefit. The operation of the prosthetic was further integrated with the application of servo motors, tendons, and sensors to enable the simulation of realistic finger movement, such as flexion and extension, upon sensing changes.

In spreading its applications, this project perpetuates proffering’s into the future. This prosthetic finger can evolve into a more sophisticated, functional apparatus through continuous improvement of materials, actuation mechanisms and sensor technologies, thereby improving the quality of life of the people who would require prosthetic assistance. Technology such as this has the promise of opening any doors for the integration of mainstream healthcare and revolutionizing accessibility to prosthetic devices through the provision of affordable, customizable, and functional solutions to any people.

REFERENCES

[1]. Manish Kumar, Krishnanand, A. Varshney, Mohammad Tawfik, Hand prosthetics fabrication using additive manufacturing, Materials Today: Proceedings, 2023.

[2]. S. Reza Kashef, Samane Amini, Alireza Akbarzadeh, Robotic hand: A review on linkage-driven finger mechanisms of prosthetic hands and evaluation of the performance criteria, Mechanism and Machine Theory, Volume 145, 2020

[3]. Hrushikesh Sayar, Jayant Karajagikar, Sojwal Deshmukh, Prosthetic limb arm for armless human, Materials Today: Proceedings, Volume 72, Part 3, 2023

[4]. Muhammad Yasir Khalid, Zia Ullah Arif, Ali Tariq, Mokarram Hossain, Kamran Ahmed Khan, Rehan Umer, 3D printing of magneto-active smart materials for advanced actuators and soft robotics applications, European Polymer Journal, Volume 205,2024.

[5]. Divya Tripathi, Kamil Reza Khondakar, Biomedical soft robotics in healthcare: Prospective, applications, and challenges, Editor(s): Kamil Reza Khondakar, Ajeet Kumar Kaushik, Next-Generation Smart Biosensing, Academic Press, 2024.

ISSN No:-2456-2165 https://doi.org/10.5281/zenodo.14637070

[6]. Ningbin Zhang, Lisen Ge, Haipeng Xu, Xiangyang Zhu, Guoying Gu, 3D printed, modularized rigid-flexible integrated soft finger actuators for anthropomorphic hands, Sensors and Actuators A: Physical, Volume 312,2020.
[7]. Zhuoqing Zhang, Guodong Liu, Zhijian Li, Wenliang Zhang, Qingjun Meng, Flexible tactile sensors with biomimetic microstructures: Mechanisms, fabrication, and applications, Advances in Colloid and Interface Science, Volume 320, 2023.
[8]. Farnaz Khoshmanesh, Peter Thurgood, Elena Pirogova, Saeid Nahavandi, Sara Baratchi,Wearable sensors: At the frontier of personalised health monitoring, smart prosthetics and assistive technologies, Biosensors and Bioelectronics, Volume 176, 2021.
[9]. Lokesh Saharan, Yonas Tadesse, Novel twisted and coiled polymer artificial muscles for biomedical and robotics applications, Editor(s): Alina-Maria Holban, Alexandru Mihai Grumezescu, Materials for Biomedical Engineering, Elsevier, 2019.
[10]. Marianna Semprini, Nicolò Boccardo, Andrea Lince, Simone Traverso, Lorenzo Lombardi, Antonio Succi, Michele Canepa, Valentina Squeri, Jody A. Saglia, Paolo Ariano, Luigi Reale, Pericle Randi, Simona Castellano, Emanuele Gruppioni, Matteo Laffranchi, Lorenzo De Michieli, Clinical evaluation of Hannes: measuring the usability of a novel polyarticulated prosthetic hand, Editor(s): Qiang Li, Shan Luo, Zhaopeng Chen, Chenguang Yang, Jianwei Zhang, Tactile Sensing, Skill Learning, and Robotic Dexterous Manipulation, Academic Press, 2022, Pages 205- 225.
[11]. Ali, Selk, Ghafari., Javad, Loghmani. (2022). Design and Construction of an Artificial Thumb Prosthetics Controlled by Index Finger.
[12]. Arbnor, Pajaziti., Genta, Rexha., Xhevahir, Bajrami., Edvin, Rustemi., J., Kola., Mehmet, Zeqiraj. (2022). Design, Manufacture and Control of the prosthetic Hand with 3D Printer. 261- 264.
[13]. Faraz, Frank, Parsa., Amir, A., Amiri, Moghadam., David, W., Stollberg., Ayse, Tekes., Cameron, W., Coates., Turaj, Ashuri. (2022). A Novel Soft Robotic Hand for Prosthetic Applications.
[14]. Buddhadeva, Das., Chandan, Chattoraj. (2023). Challenges and Solutions in Design and Fabrication of Finger Prosthesis.
[15]. Valentina, A., Yurova., Gleb, Velikoborets., Andrei, Vladyko. (2022). Design and Implementation of an Anthropomorphic Robotic Arm Prosthesis.
[16]. Antonia, Georgopoulou., Kai, Junge., L., Eckey., Simon, Rogler., Robert, K., Katzschmann., Josie, Hughes., Frank, Clemens. (2023). A multi-material robotic finger with integrated proprioceptive and tactile capabilities produced with a circular process.
[17]. Ketut, B., Putra., Nathan, Montgomery., Samira, Kalamdani., Lei, Chen., Brian, Kelly., Jeffrey, Wensman., Albert, J., Shih. (2023). Fabrication and assessment of partial finger prostheses made using 3D-printed molds: A case study. Prosthetics and Orthotics International
[18]. Saurabh, Srivastava., Sachin, Salunkhe., Sarang, Pande., Vishal, Naranje. (2021). Design of Prosthetic Finger Using Topology Optimization.
[19]. Akash, Jain., Deepanshika, Gaur., Chinmay, Bindal., Ranganath, M., Singari., Mohd., Tayyab. (2021). Design of an Auxiliary 3D Printed Soft Prosthetic Thumb.
[20]. Li, Tian., Jianmin, Zheng., Yiyu, Cai., Muhammad, Faaiz, Khan, Bin, Abdul, Halil., Nadia, Magnenat, Thalmann., Daniel, Thalmann., Hanhui, Li. (2021). Fast 3D Modeling of Prosthetic Robotic Hands Based on a Multi-Layer Deformable Design.