

Optimizing Robotic Arm Performance: A Finite Element Analysis Comparison to Nylon, PLA, and ABS

Prashant Kumar^{1,*}, P. K. Sharma², Ishan Khan³

Abstract

This paper analyzes the mechanical behavior of three materials used in robotic arms: Nylon, PLA, and ABS, with an emphasis on three important parameters: total deformation and equivalent stress in different conditions of loading. In this regard, a finite element analysis was applied via the ANSYS software to simulate structural stiffness as well as their resistance against stress that these materials undergo when strengthened with steel reinforcements. The investigation shows that the performance of Nylon, especially when reinforced with steel, is excellent compared to PLA and ABS in terms of deformability and spread in stress distribution. Therefore, it is more applicable to applications that include higher durability along with minimum deformation when load is applied. The general design and analysis shall indicate some valuable insights in the design of small-scale robotic arms to be used in industries as well as educational institutions.

Keywords: ABS, ANSYS, equivalent stress, FEA, material performance, nylon, PLA, robotic arm, steel reinforcement, total deformation

INTRODUCTION

Robotic arm assisted technology has become increasingly popular in orthopaedic surgery in recent years, particularly in joint arthroplasty. The robotic arm–hand teleoperation is gaining importance in fields, such as defense, space, volcano exploration, mining, medical, nuclear, maintenance and service, and underwater operations to ensure the prime concern on human safe [1]. Artificial intelligence (AI) encompasses a range of intelligent technologies that can learn, reason, and make decisions without explicit programming. In the medical field, AI is finding increasing applications in various areas, including medical imaging analysis and diagnosis, drug discovery and development and robot–assisted surgery [2]. In today’s industries, we find many of the heavy–lifting tasks are being worked on by large

automated mechanical robotic arms. A common task associated with these robotic arms is to pick up an object and place it at a desired position. The robotic arm is a forward kinematics problem. The arm structure is made of many elements connected by linkages or joints. The application involves the use of actuators to move different elements of the arm to a specific (x, y, and z) position. The design of these arms involves the knowledge of many factors of which the important ones are the degrees of freedom, torques, and the equations of motion [3].

The image depicts a multi–joint robotic manipulator, showing its reference coordinate

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system (X, Y, Z) and several rotary joints connected by links. Each joint has joint variables, which represent the angles of rotation that control the arm's movement. The end-effector, positioned at the tip of the arm, interacts with the environment and can be a tool or gripper. The position and orientation of the end-effector depend on the combined rotations of the joints and the lengths of the links. This system is used in robotics to perform precise tasks through forward and inverse kinematics [4].

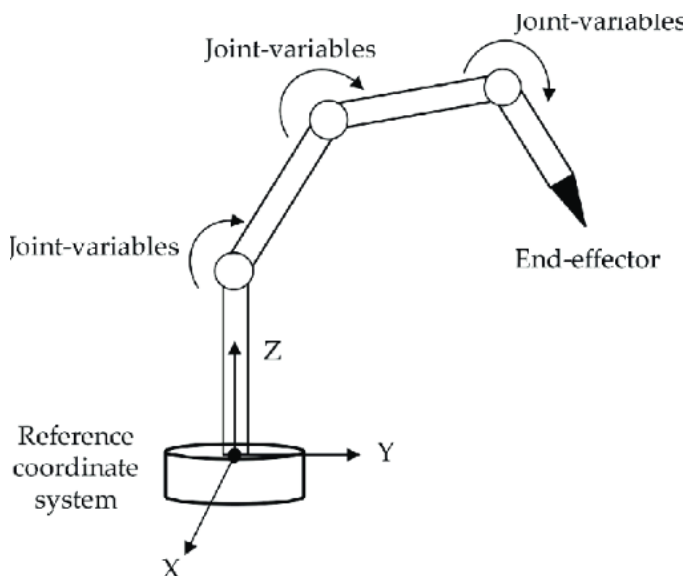


Figure 1. Robotic Manipulator or Industrial Robot [4].

TYPES OF ROBOTIC ARM

There are many types of robotic arms, including:

Cartesian Robotic Arm

It is known as gantry robotic arms, are composed of three articulating joints designed to move linearly in three dimensions utilizing X, Y, and Z coordinates (Figure 2A). Further rotary capability is frequently provided by the wrist joint. Cartesian robotic arms are based on motors and actuators to manipulate 3D printing tools, whose movements are restricted to a linear manner horizontally and vertically. Current 3D bioprinters commonly adapt cartesian coordinate robotic arms in extrusion-based and inkjet bioprinting. Despite its broad application in conventional 3D bioprinting modalities, it is incapable of printing on anisotropic or curved surfaces [5].

SCARA Robotic Arm

The Selective Compliance Articulated Robot Arm (SCARA) robot which will be mainly discussed in this research paper. SCARA robots have high precision and accuracy at the same time power efficiency as there is only 1 joint which is joint 3 need to operate against gravity force. Therefore, the SCARA robot is a good choice for an industry that requires high precision and low power consumption. To achieve high accuracy, the SCARA robot requires an advanced controller to handle and control the nonlinear dynamic behavior of the robot system [6].

LITERATURE REVIEW

In their 2024 study, Sengaphone P, et al. [7] investigated the developments in robotic technology as they relate to tomato harvesting, Emphasizing different end effectors made for this difficult undertaking. The report highlights the benefits and present applications of several end-effector types, including grippers, rotary tools, scissors methods and suction devices, by examining literature from sources, such as Animo Search, Google Scholar, Scopus, and IEEE Xplorer. It explains how these technologies separate fruit, make use of sensors for improved performance, and take design requirements, such as

fruit–shape adaptation into consideration. The paper also discusses the problems these end effectors are expected to face and the solutions as well as directions for further research on the subject. Methods for tomato harvesting must be developed to be more environmentally friendly and efficient by improving detection, introducing AI, and making the entire system adaptable.

According to Hamou S, et al. 2024 [8], a robotic arm is among those mechanical systems that have a certain number of DoF (Degrees of Freedom) and mimics a human arm that can perform any task in hand whatever it may be, be it holding or moving objects. The focus of the current study was to design artificial human parts and robots that can perform activities by converting brain signals into activities. Due to BCI devices, individuals with motor limitations are now able to operate assistive robotic machinery that restores lost functions. This study provides an overview of the most recent state–of–the–art research on electroencephalogram (EEG)–based robotic arm control. An analysis is carried out to compare the various approaches and strategies applied in the various blocks of the noninvasive BCI controlling system for the robotic arm. Feature extraction, categorization, command, signal preprocessing, and noninvasive electrode signal capture are some of these building pieces. This research also provides a performance comparison of the robotic arms controlling systems that were assessed utilizing EEG signals.

Sumiyama K. and Tada N. (2024) [9]. Originally created for tissue sampling and diagnostics, flexible endoscopy has been modified for therapeutic purposes, resulting in the development of natural aperture transluminal endoscopic surgery (NOTES) in the 2000s. Due to the requirement for a triangulation function to improve NOTES’s safety and intuitiveness, dual–arm flexible endoscopic robotic platforms have been developed. While interest in NOTES has waned globally over the past ten years, current research and development is seeing the application of no–scar surgical concepts to other challenging endoluminal operations, including Endoscopic Full-Thickness Resection (EFTR) and Endoscopic Submucosal Dissection (ESD). Robotics in flexible endoscopy has the potential to accelerate the global adoption of these treatments by facilitating their standardization. Various robotic platforms have been developed and tested in preclinical and clinical settings to demonstrate their efficacy and safety. In this article, we study the publications on technology and elucidate their advantages and existing challenges.

Abryandoko E. W., et al. (2024) [10] performed this study recent advancements in human–robot interaction (HRI) for rehabilitation, focusing on the integration of functional electrical stimulation (FES) with robotic arms to enhance post–stroke motor recovery. It highlights the potential of combining FES and robotic devices to achieve precise motor goals by aligning muscle stimulation with individual patient needs, thus addressing the challenge of muscle fatigue caused by constant voltage amplitudes. By examining nine rehabilitation systems through literature from IEEE–Xplore, Scopus, and PubMed, the study critically compares designs, actuators, and technological challenges, while exploring emerging trends in HRI for rehabilitation and the future potential of hybrid neuroprosthesis systems.

In 2021, Medtronic introduced the Hugo Robotic–Assisted Surgery (RAS) System, presenting a modular alternative to the established market leader, the Intuitive da Vinci (DV) surgical system Ngu, J. C. Y., et al. (2024) [11]. A detailed technical study of the Hugo RAS was conducted to explore the strengths and weaknesses of this new robotic surgical system. Each component of the system – vision tower, arm cart, and surgeon console – was compared against the existing DV systems. The docking process, instrumentation, and external arm movement trajectories were analyzed. The modular Hugo RAS provides the possibility of operating using up to four arm carts. It has certain design features that are unique to itself, and others that have been implemented to address the shortcomings of the DV SI. While Medtronic’s first–generation robot offers distinct advantages over the older intuitive systems, the true test of its mettle will be its performance compared to the latest DV Xi.

OBJECTIVES

- Evaluate and compare the mechanical performance of Nylon, PLA, and ABS materials for robotic arms.
- Analyze total deformation and equivalent stress under varying loads for these materials.
- Determine the impact of steel reinforcement on Nylon's structural stiffness and stress resistance.
- Assess whether Nylon outperforms PLA and ABS in terms of deformation and dimensional stability under similar loads.
- Guide material selection for robotic arms in applications requiring minimized deformation and stress.

RESEARCH METHODOLOGY

This study uses Finite Element Method (FEM) for static structural analysis of a robotic arm, focusing on applications in small-scale industrial, educational, and household settings. Industrial robotic arms, also known as articulated robotic arms, are widely used in manufacturing, automotive, and agriculture due to their precision, speed, and programmability. This research examines the structural suitability of Nylon for these robotic arms through an ANSYS simulation. The paper would include designing and analyzing a six-degree-of-freedom robotic arm, where the modeling process and customization can be catered to by Ansys software.

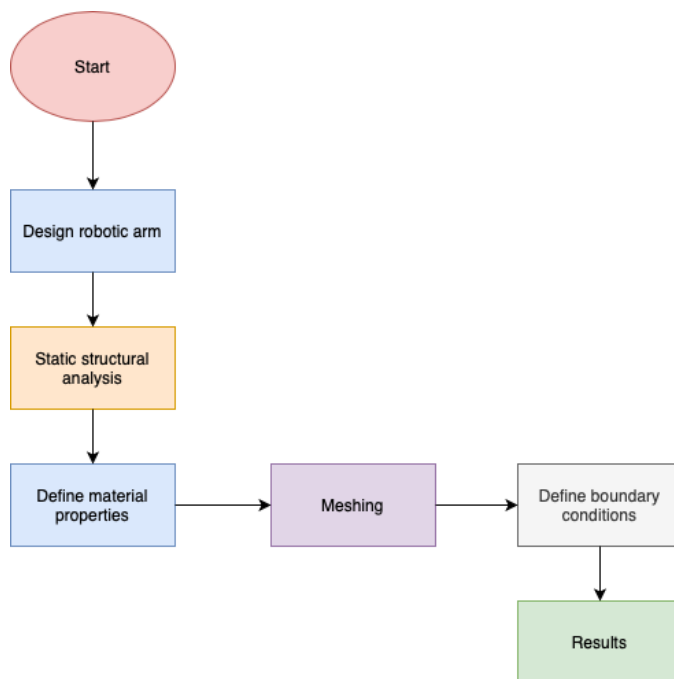


Figure 2. Methodology Adopted.

This flowchart represents the steps to follow in doing the Finite Element Analysis FEA for robotic arms by using software like ANSYS.

- *Start:* Deem the project as a start for the sake of analysis and optimization of the design for the robotic arm.
- *Robotic Arm Design:* Use CAD software to create an accurate detailed model of robotic arms.
- *Static Structural Analysis:* Analysis of the response of the robotic arm under static loads to study the principles of stress, strain, and deformation.
- *Material properties:* Define material properties, such as density, Young's modulus, Poisson's ratio, yield strength are those that affect the behavior of the arm under loads.

- *Mesh*: It discretizes the model externally and further renders a mesh for numerical simulation using a high-quality mesh to increase precision.
- *Boundary Conditions*: These describe the constraints and loads applied on the boundary to simulate actual practice conditions like fixed support, forces, and moments.
- *Results*: Compute and interpret distributions of stress, strain, and displacement within the robot arm during its analysis process.

MODELLING OF ROBOTIC ARM

What is basically necessary when developing a robotic arm in SOLIDWORKS is that the geometry should be correctly represented through the 3D model. Generally, this involves links, joints, and end-effectors. Drawing and feature-based methods like extrusions, through Boolean operations, are thus used to combine the parts together, while appropriate dimensioning and positioning ensure that the parts copy the actual design. Constraints and part relationships finally, are introduced to achieve correct movement modeling. The 3D model then becomes the foundation structure in creating meshing, material properties, and finite element analysis to analyze the arm under varied conditions in terms of performance.



Figure 3. CAD Model of Robotic Arm.

The implementation of geometry structure is based on existing literature. The three instances listed below are examined in this study to assess the robotic arm's performance.

FINITE ELEMENT ANALYSIS OF A ROBOTIC ARM

Within engineering studies, there exist traditional and computational approaches. Traditional methods make use of physical experiments as well as theoretical models, whereas computations rely on a more advanced technology to simulate complexity as well as optimize designs. FEA is a cornerstone computational technique that model structures by breaking the structure down into much smaller elements, analyzing each individual one, and then combining results to predict behavior under different conditions. With such an approach, design, testing, and optimization are enhanced-that is, one would support and move forward the more conventional methods towards more accurate and creative solutions.

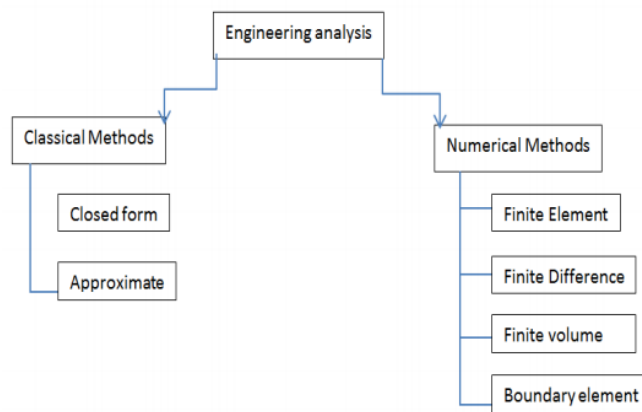


Figure 4. FEM approach.

Using SOLIDWORKS, the 3D model of robotic arm is made with structural and geometrical accuracy. This model is exported using Creo in an IGES file and imported into ANSYS. In ANSYS, a new study is created wherein the 3D model is selected and material properties are defined. The model is meshed, and boundary conditions are given. The analysis focuses on three solutions: Total Deformation, Von Mises Stress, and Safety Factor.

MESHING

In ANSYS, the robotic arm is represented using a Cartesian coordinate system defined by eight degrees of freedom per node: translations along the x, y, and z axes. This setup accommodates various material behaviors, including resistance, flexibility, and deformation potential. The system can model deformations in nearly incompressible elastoplastic materials and fully incompressible hyperelastic materials. Figure 3.4 illustrates the shape, node locations, and coordinate system for the component. The input data includes both nodes and properties for orthotropic or anisotropic materials, reflecting the element's orientation in these directions.

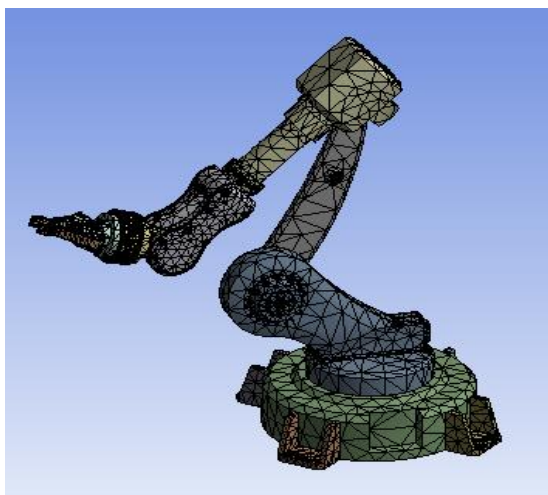


Figure 5. Robotic Arm Mesh Model.

LOADS AND BOUNDARY CONDITIONS

This step aims to provide boundary conditions and input loading on the model. The boundary conditions used in this study were following Santosh et al. (2022), which were chosen to be applied in all directions. Static loading is applied to all design models with identical boundary conditions. For this static structural analysis, a load of 2 to 3 N is applied on the surface of the gripper. These boundary conditions are in accordance with the study of Santosh et al. (2022).

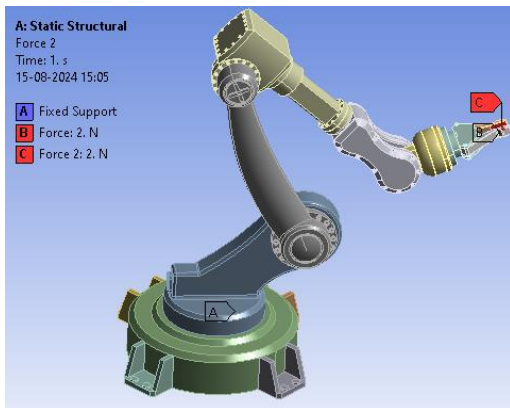


Figure 6. Load and boundary conditions.

RESULTS AND DISCUSSION

This study investigates the use of Nylon (Polyamide) as a substitute for PLA and ABS in the analysis of a robotic arm using ANSYS software. The primary focus is on evaluating the total deformation (the amount of shape change) and equivalent stress (the stress distribution within the material) when the robotic arm is subjected to different loads—1N, 2N, and 3N. The results from Nylon are compared to the performance of PLA and ABS under the same conditions to assess which material performs better in terms of strength and flexibility. The detailed findings of these comparisons are presented in the subsequent sections of the study. The objective is to determine whether Nylon, due to its material properties, offers improved mechanical performance over PLA and ABS, particularly in scenarios requiring higher durability and stress resistance. By analyzing these factors, the study aims to guide the selection of materials for robotic arms in practical applications.

TOTAL DEFORMATION

Table 1. Total deformation results.

Materials	Load, N	Total deformation, mm (Santosh et al. (2022))	Total deformation, mm Present study
PLA	1	3.4	–
PLA + Steel	1	2.8	–
Nylon	1	–	2.5
Nylon + Steel	1	–	2.1

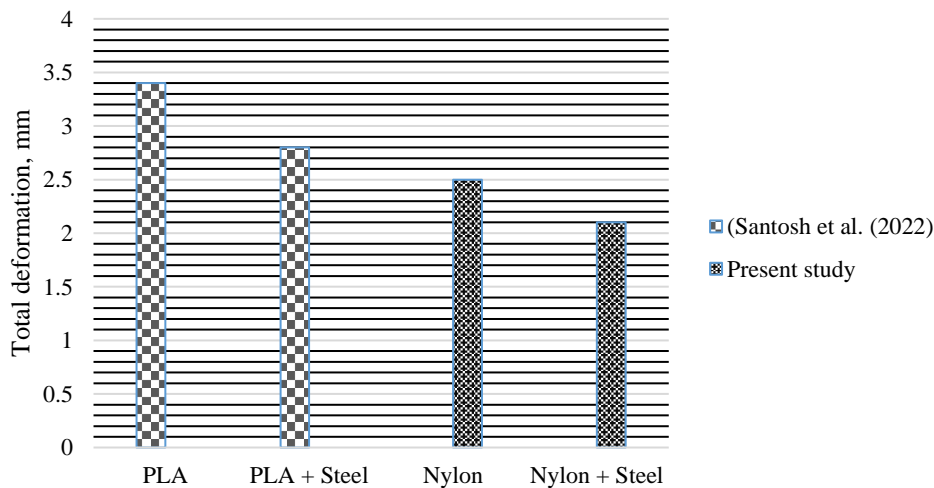


Figure 7. Comparison and variation of total deformation with different materials.

Four scenarios were analyzed in ANSYS for the robotic arm: 1) the entire arm with PLA, 2) the gripper’s support with steel and the rest with PLA, 3) the entire arm with Nylon, and 4) the gripper’s support with steel and the rest with Nylon.

EQUIVALENT STRESS

Four scenarios were analyzed in ANSYS: 1) the robotic arm entirely with PLA, 2) the gripper support with steel and the rest with PLA, 3) the entire arm with Nylon, and 4) the gripper support with steel and the rest with Nylon.

Table 2. Equivalent stress results.

Materials	Load, N	Equivalent Stress, MPa (Santosh et al., 2022)	Equivalent Stress, MPa Present Study
PLA	1	29.9	–
PLA + Steel	1	82.3	–
Nylon	1	–	20.9
Nylon + Steel	1	–	74.8

Comparing equivalent stress results, significant differences are observed between Santosh et al. (2022) and this study. Santosh et al. report PLA stress at 29.9 MP a under 1 N load, increasing to 82.3 MPa with steel reinforcement due to added stiffness. In contrast, this study finds Nylon at 20.9 MPa under the same load, demonstrating better stress distribution. With steel reinforcement, Nylon + Steel reaches 74.8 MPa, which, while higher than Nylon alone, is lower than PLA + Steel, indicating better overall stress performance for Nylon + Steel.

COMPARISON OF NYLON WITH ABS

Table 3. Total deformation comparison of Nylon with ABS.

Materials	Load, N	Total deformation, mm (Santosh et al., 2022)	Total Deformation, mm Present Study
ABS	2	8.1	–
	2.5	9.9	–
	3	12.1	–
Nylon	2	–	6.4
	2.5	–	8.5
	3	–	10.7

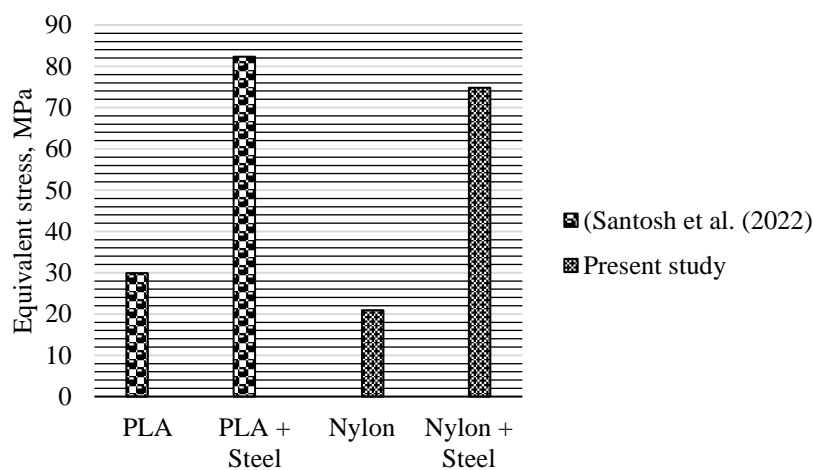


Figure 8. Comparison and variation of equivalent stress with different materials.

At a 2 N load, Nylon deforms 6.4 mm compared to 8.1 mm for ABS, showing a 20.9% improvement. At 2.5 N, Nylon deforms 8.5 mm versus 9.9 mm for ABS, a 14.1% improvement. Under the maximum load of 3 N, Nylon deforms 10.7 mm while ABS deforms 12.1 mm, reflecting an 11.6% improvement.

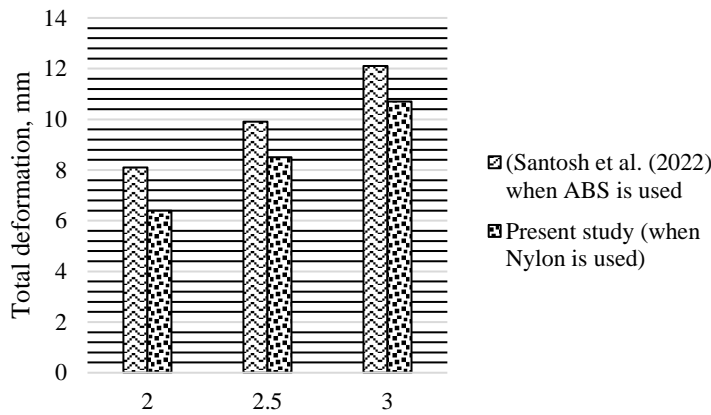


Figure 9. Total deformation comparison of Nylon with ABS.

Table 4. Equivalent stress comparison of Nylon with ABS.

Materials	Load, N	Equivalent Stress, MPa (Santosh et al., 2022)	Equivalent Stress, MPa Present Study
ABS	2	222.3	–
	2.5	272.6	–
	3	333.5	–
Nylon	2	–	194.6
	2.5	–	224.5
	3	–	284.4

An equivalent stress comparison of Nylon and ABS shows that Nylon performs better under each load applied. Loaded with a 2 N load, the stress equivalent is 194.6 MPa, much lower than ABS, which is 222.3 MPa, thus a betterment of around 12.5%. When loaded with a 2.5 N load, Nylon looks for an equivalent stress amounting to 224.5 MPa in comparison to ABS’s 272.6 MPa representing a large improvement of 17.6 per cent. At that load, when identical loading conditions increase to 3 N, equivalent stress of Nylon registers at 284.4 MPa again below that of ABS at 333.5 MPa, and now an improvement of a little over 14.7%. These results would, therefore, suggest that Nylon can manage stress more effectively as load moves to any of the said graded levels, clearly making it a better material choice when stress resistance is critical.

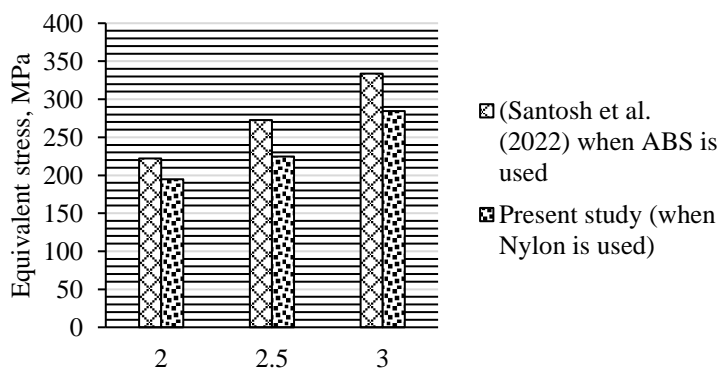


Figure 10. Equivalent stress comparison of Nylon with ABS.

COMPARISON OF NYLON WITH PLA

Table 5. Total deformation comparison of Nylon with PLA.

Materials	Load, N	Total Deformation, mm (Santosh et al., 2022)	Total Deformation, mm Present Study
PLA	2	5.6	–
	2.5	6.9	–
	3	–	–
Nylon	2	–	3.4
	2.5	–	5.1
	3	–	7.7

Nylon consistently outperforms PLA in resisting deformation across all tested loads. At 2 N, Nylon deforms 3.4 mm compared to PLA’s 5.6 mm, reflecting a 39.3% improvement. At 2.5 N, Nylon deforms 5.1 mm versus PLA’s 6.9 mm, showing a 26.1% improvement. Under a 3 N load, Nylon’s deformation is 7.7 mm compared to PLA’s 8.5 mm, resulting in a 9.4% improvement. Overall, Nylon offers superior deformation resistance, making it more suitable for applications requiring minimal deformation.

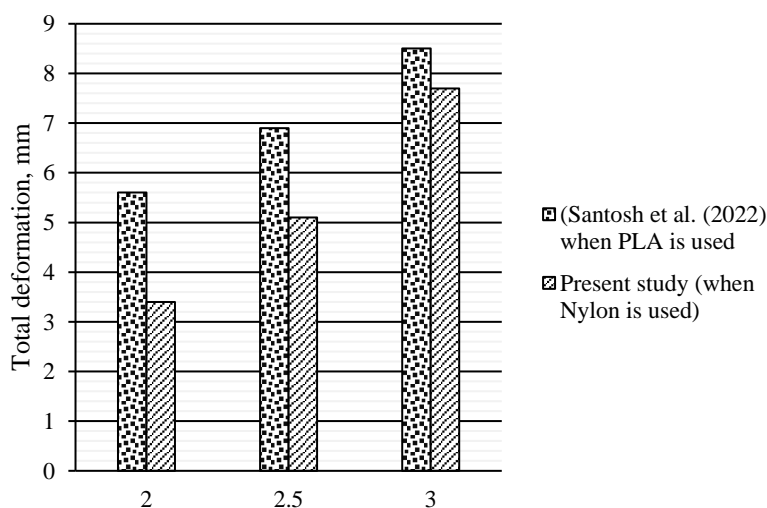


Figure 11. Total deformation comparison of Nylon with PLA.

Table 6. Equivalent stress comparison of Nylon with PLA.

Materials	Load, N	Equivalent Stress, MPa (Santosh et al., 2022)	Equivalent Stress, MPa Present Study
PLA	2	164.6	–
	2.5	201.8	–
	3	246.8	–
Nylon	2	–	157.8
	2.5	–	194.6
	3	–	224.5

Nylon consistently shows lower equivalent stress compared to PLA under all tested loads, indicating better stress management. At 2 N, Nylon’s equivalent stress is 157.8 MPa, 4.2% lower than PLA’s 164.6 MPa. At 2.5 N, Nylon exhibits 194.6 MPa, outperforming PLA’s 201.8 MPa by 3.6%. At the maximum load of 3 N, Nylon’s stress is 224.5 MPa, compared to PLA’s 246.8 MPa, reflecting a 9.1%

improvement. Overall, Nylon effectively distributes stress better than PLA, making it more suitable for stress-resistant applications.

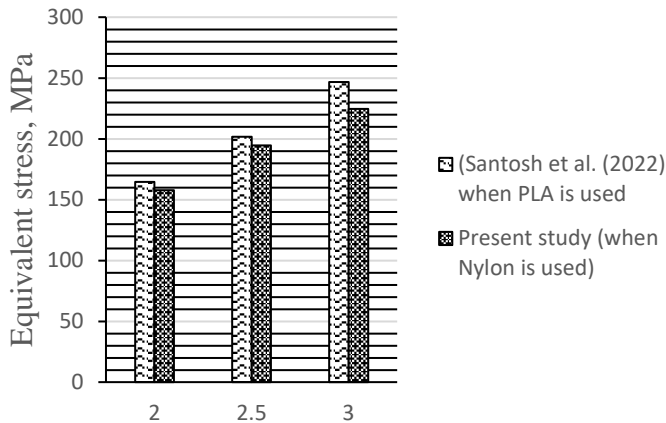


Figure 12. Equivalent stress comparison of Nylon with PLA.

CONCLUSIONS

In this study, Nylon material is introduced as a substitute for PLA and ABS for the analysis of robotic arms using ANSYS. The results have been seen under total deformation and equivalent stress with the variation of applied loads of 1N and 2 to 3N. Then, the values of total deformation and equivalent stress are compared with Nylon PLA and ABS. In this chapter, the following conclusions are discussed as follows.

The total deformation values obtained in this study are the lowest for Nylon + Steel with a 1 N load, at 2.1 mm, outperforming plain Nylon at 2.5 mm. This essentially proves that adding steel reinforcement enhances the structural stiffness of Nylon. For comparison, data obtained by Santosh et al. (2022) show that PLA exhibited higher deformation at 3.4 mm and PLA + Steel at 2.8 mm.

It can be derived from the simulation results that, under a 1 N load, Nylon + Steel has an equivalent stress of 74.8 MPa, indicating that there is a dramatic rise in stress resistance due to reinforcement. In plain Nylon, this value is 20.9 MPa, which means that the addition of steel to the base material enhances the ability of the material to bear stresses. In contrast, in the data provided by Santosh et al. (2022), PLA has an equivalent stress of 29.9 MPa and PLA + Steel has an equivalent stress of 82.3 MPa.

ABS, total deformation with load is 8.1 mm at 2 N, 9.9 mm at 2.5 N, and 12.1 mm at 3 N, as recorded by Santosh et al. (2022). The Nylon in the present study also undergoes increasing deformation with an increase in load: 6.4 mm at 2 N, 8.5 mm at 2.5 N, and 10.7 mm at 3 N. This means that, for the same loading conditions, nylon will show less total deformation than ABS and, therefore, better dimensional stability.

The increase in ABS equivalent stress with an increase in load is shown: 222.3 MPa at 2 N, 272.6 MPa at 2.5 N, and 333.5 MPa at 3 N. Nylon, as noted in this study, has a similar trend of increase with loads: 194.6 MPa at 2 N, 224.5 MPa at 2.5 N, and 284.4 MPa at 3 N. Although at every single level of load, nylon is under lower equivalent stress compared to ABS, the stress in nylon increases with load significantly, and this suggests that while nylon has lower resistance to stress than ABS, it still performs effectively under increasing loads.

PLA shows increasing total deformation with load: 5.6 mm at 2 N, 6.9 mm at 2.5 N, and 8.5 mm at 3 N. In the present study, Nylon exhibits lower deformation values: 3.4 mm at 2 N, 5.1 mm at 2.5 N, and 7.7 mm at 3 N. This indicates that Nylon consistently deforms less than PLA under equivalent

loads, suggesting that Nylon may offer better performance in applications where reduced deformation is crucial.

PLA is under increasing equivalent stress: 164.6 MPa at 2 N, 201.8 MPa at 2.5 N, and 246.8 MPa at 3 N. In this study, Nylon demonstrates slightly smaller stress values: 157.8 MPa at 2 N, 194.6 MPa at 2.5 N, and 224.5 MPa at 3 N. That means at all levels of load Nylon is under a smaller equivalent stress compared to PLA, which may indicate better performance in applications where smaller stress is required.

REFERENCES

1. Kurpath MI, Kumar AP, Bodireddy J, Chandrasekaran K, Sam KN. An IMUs and potentiometer-based controller for robotic arm-hand teleoperation. *Sensors and Actuators A: Phys.* 2024 Jan; 11:115019.
2. Iftikhar M, Saqib M, Zareen M, Mumtaz H. Artificial Intelligence: Revolutionizing Robotic Surgery. *Ann Med Surg.* 2024 Sep1;86(9):5401–9.
3. Patidar V, Tiwari R. Survey of robotic arm and parameters. In the 2016 Int Conf Comput Commun Inform, IEEE. 2016Jan7;1–6.
4. Garbi GP, Grandinetti FJ. Kinematic Model for Project Scheduling with Constrained Resources Under Uncertainties. *Intech Open. In Kinematics 2017 Dec 20.*
5. Li K, Huang W, Guo H, Liu Y, Chen S, Liu H, et al. Advancements in Robotic Arm-based 3D Bioprinting for Biomedical Applications. *Life Med. Inad046, 2023 Dec1;2(6).*
6. Tay SH, Choong WH, Yoong HP. A Review of SCARA Robot Control System. In 2022, Int Conf Artif Intell Eng Technol, IEEE. 2022 Sep13;1–6.
7. Senga phone P, De Leon JM, Concepcion R, Bandala AA, Augusto GL, Naguib R, et al. End effectors of the robotic arms for tomato harvesting: A Comprehensive Review. *J Comput Appl Res Mech Eng* , 2024 Jul 10.
8. Hamou S, Moufassih M, Tarahi O, Agounad S, Azami HI, Mazid A. Comprehensive Review of Noninvasive Brain-Computer Interfaces for Controlling Robotic Arms. *J Med Robot Res.* 2024 Apr;19:2430001.
9. Tada N, Sumiyama K. Robotic Platforms for Therapeutic Flexible Endoscopy: A Literature Review. *Diagnostics.* 2024 Mar11;14(6):595.
10. Abryandoko EW, Susmartini S, Laksono PW, Herdiman L. Literature Review: User interface of system functional electrical stimulation (FES) and arm robotic rehabilitation. *J Appl Eng Sci.* 2024 Mar; 6:1–4.
11. Ngu JC, Lin CC, Sia CJ, Teo NZ. A narrative review of the Medtronic Hugo RAS and technical comparison with the Intuitive da Vinci robotic surgical system. *J Robot Surg.* 2024 Feb 28;18(1):99.