International Journal of Research Publication and Reviews

Journal homepage: www.ijrpr.com ISSN 2582-7421

# Comparative Structural Analysis of Steel and Aluminum 356 Articulated Robotic Arms for Material Handling

***[1]GYANDEEP SINGH, [2]. AAKASH, [3]. AAKASH AMRITRAJ, [4]. AJAY SOLANKI***

DELHI TECHNOLOGICAL UNIVERSITY

**ABSTRACT :**

Articulated robotic arms are increasingly significant in industrial applications due to their precision and ability to perform heavy-duty tasks. This paper presents the design and analysis of such a robotic arm intended for material handling. The design and simulation of the arm, including its gripper, were carried out using CATIA software. Finite Element Method (FEM) analysis was incorporated during the early design phase to evaluate structural performance. ABAQUS was employed to analyze the arm under varying materials and load conditions. The results of this analysis highlight the design's strengths and limitations, aiding in the selection of optimal materials and confirming the feasibility of the proposed robotic arm.

## 1. Introduction

Robotics is a multidisciplinary field focused on the design, development, and use of robots. In today's world, robots are widely integrated into daily life, especially in industrial and manufacturing settings. They perform various tasks such as welding, painting, cutting, polishing, drilling, assembly, packaging, and quality testing. Robots are valued in these industries for their precision, consistency, and ability to operate without fatigue—offering a clear advantage over human labor in repetitive and high-precision tasks.

As demand grows for robots capable of handling more complex and diverse operations, the development of efficient, multi-functional robots becomes increasingly vital. Robots generally fall into two categories: **service robots**, which assist in reducing the workload on humans and machines, and **industrial robots**, which are fully automated systems used in manufacturing processes. Industrial robots often take the form of robotic arms composed of interconnected links, joints, sensors, and controllers. One end of the arm is fixed to a base, while the other end features a tool or gripper used to perform specific tasks. These electro-mechanical systems are controlled by computer programs that direct the movement of joints and end effectors.

The design of the robotic arm plays a critical role in its performance. Proper sizing and structure are essential an arm that is too large or too small may not function efficiently within a given workspace. The primary objective of using robotic arms is to minimize human error, reduce manual effort, and enhance productivity.

There are five commonly used robot configurations: **SCARA** (Selective Compliance Assembly Robot Arm), **articulated**, **Cartesian**, **cylindrical**, and **spherical**. Among these, articulated robotic arms are widely used in high-volume production industries due to their flexibility, reach, and precision. Mechanical grippers attached to the arm's end-effector are utilized for operations such as picking, placing, loading, and unloading materials like pallets, food products, and metal sheets. These tasks, traditionally labor-intensive and physically demanding, are well-suited for robotic automation.

## 2. Problem Formulation

A review of various studies highlights that understanding the components and structure of a robotic arm can be complex and time-consuming. However, using 3D modeling software significantly simplifies this process by allowing for the creation of detailed and accurate virtual models. This approach enables designers to analyze the arm's design, functional requirements, and behavior prior to physical fabrication. It is a cost-effective method that minimizes errors during development and allows for easy modifications to accommodate evolving requirements or design changes.

## 3. Methodology

- The initial step involves gathering the functional requirements of the robotic arm and representing them through a 2D sketch.
- Based on this, a detailed 3D solid model is developed in **CATIA** using appropriate commands and design constraints.
- The completed 3D model is then imported into **ABAQUS** for structural analysis.
- Suitable materials are selected for different components of the robotic arm to ensure strength and performance.
- A mesh is generated, and relevant boundary conditions are applied to simulate realistic working conditions.
- The arm is analyzed under various loading conditions to observe deformation and identify stress concentration zones, enabling in-depth evaluation of the design's structural integrity.

### *3.1. CAD Modeling*

**Computer-Aided Design (CAD)** refers to the use of computer technology to create, modify, analyze, or optimize a design. CAD software enhances the efficiency of the design process by enabling faster development, improved design quality, better communication, and the generation of manufacturing data. Typically, CAD is implemented through a computer graphics system known as a CAD system.

In this project, each component of the robotic arm is individually designed using **CATIA**, after which they are assembled by applying appropriate constraints. **CATIA** is selected due to its widespread use in robotic design, as it significantly reduces development time, enhances designer productivity, and improves modeling accuracy. Figures 1.1 to 1.7 illustrate the individual components of the robotic arm, while Figure 1.8 presents the fully assembled model.

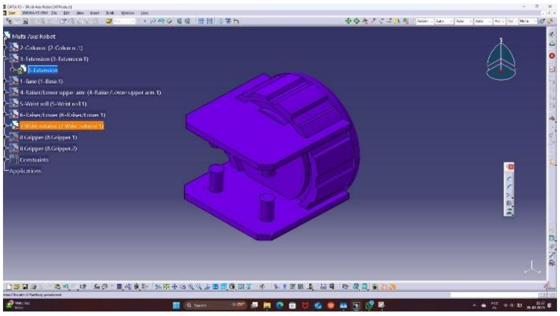


**Figure :1.1**

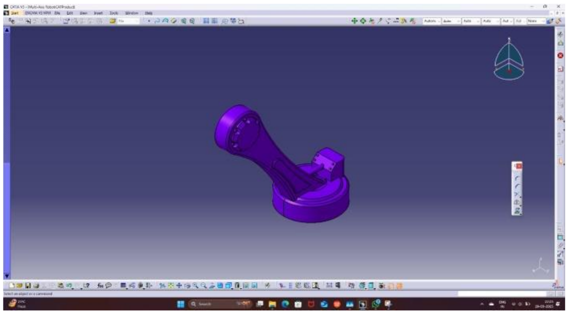


**Figure: 1.2**

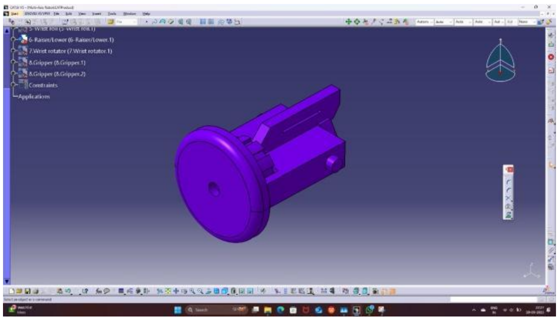


**Figure : 1.3**

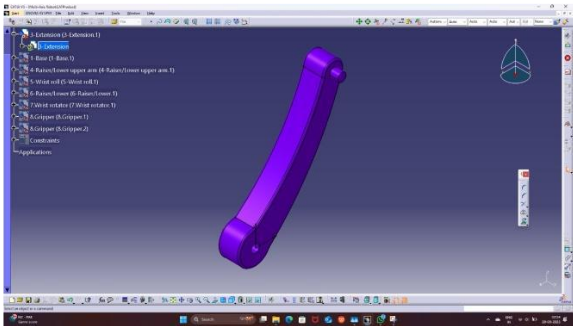


**Figure : 1.4**

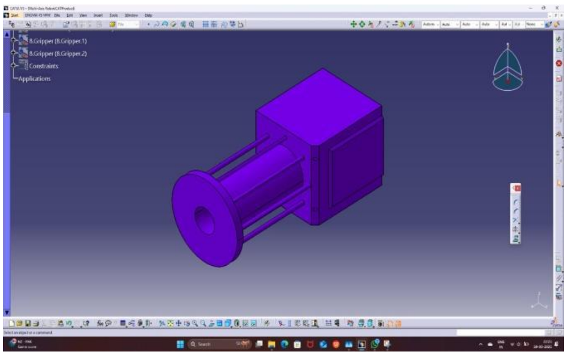


**Figure : 1.5**

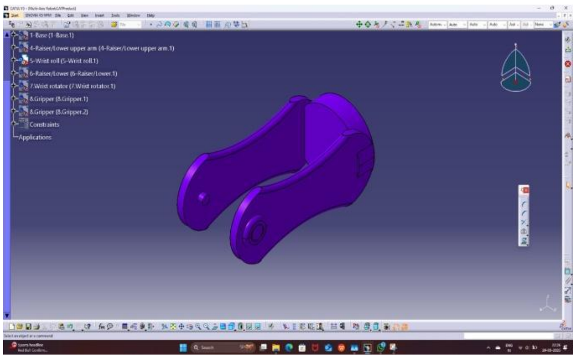


**Figure : 1.6**

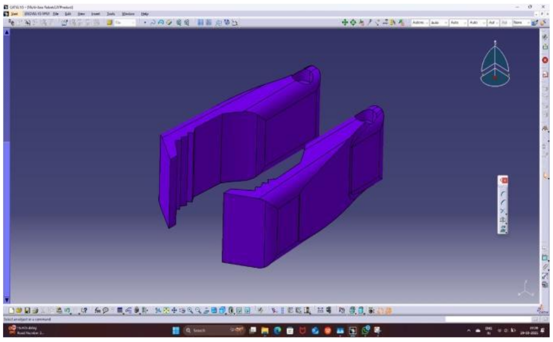


Figure : 1.7

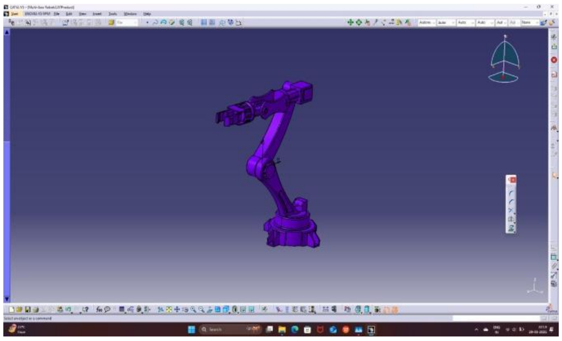


Figure : 1.8

### *3.2. Structural Analysis*

The **Finite Element Analysis (FEA)** results reveal the stress distribution within a structure subjected to specific loading conditions. To conduct an accurate FEA, it is essential to define the geometry of the arm, the finite element model, boundary conditions, and the nature and locations of applied loads. These loading conditions significantly influence the analysis outcomes. FEA is particularly useful for identifying stress concentrations and evaluating the response of individual components to various forces. In this study, all components are assumed to exhibit **linearly elastic behavior** [12], simplifying the analysis while providing reliable insights. Compared to physical testing, FEA is a cost-effective and time-saving method for evaluating structural performance. The 3D model created in **CATIA** is exported in **STEP or IGS format** for compatibility with analysis software. **ABAQUS** is used for the simulation, employing its **static structural analysis module** to assess stress distribution and deformation across the robotic arm components.

### *3.3. Meshing*

The process of **discretization** involves dividing the model into numerous small elements to ensure that applied loads are evenly distributed across the structure. This is a fundamental step in the Finite Element Analysis (FEA), where the model is broken down into a finite number of elements. The accuracy of the FEA results is influenced by the number and size of these elements finer meshes generally lead to more precise outcomes. In this study, the robotic arm model is finely meshed using **triangular elements**, providing better resolution in capturing stress variations across complex geometries. A total of **10 nodes** are used in the mesh to define the structure and enable accurate simulation.

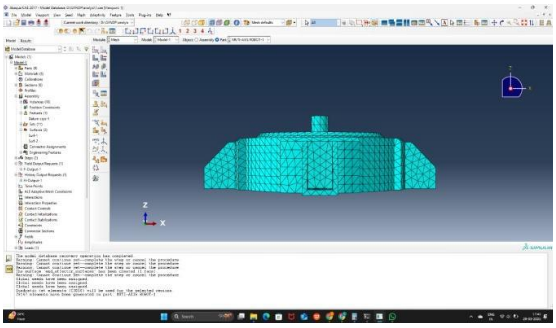


Figure : 2.1

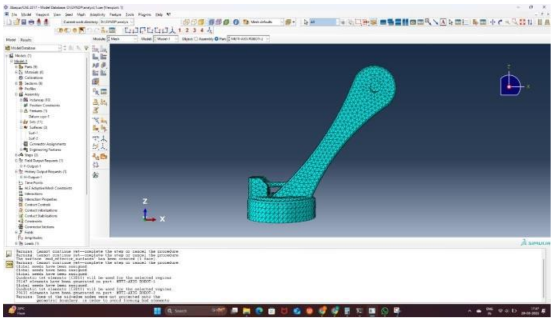


Figure : 2.2

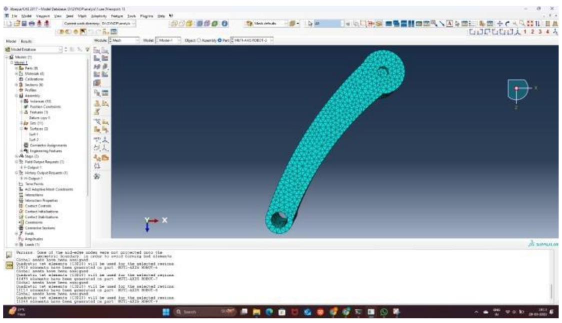


Figure : 2.3

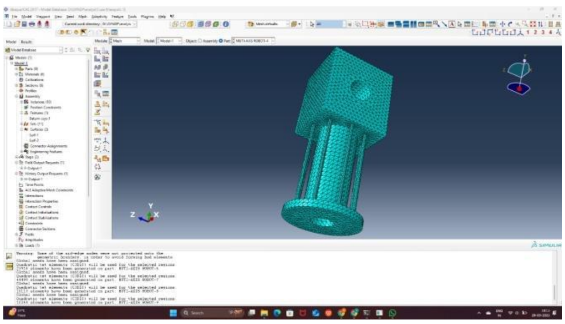


Figure : 2.4

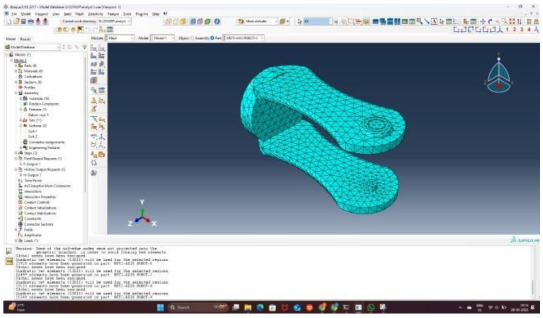


Figure :2.5

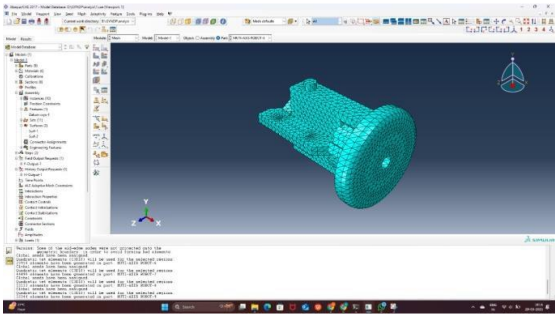


Figure : 2.6

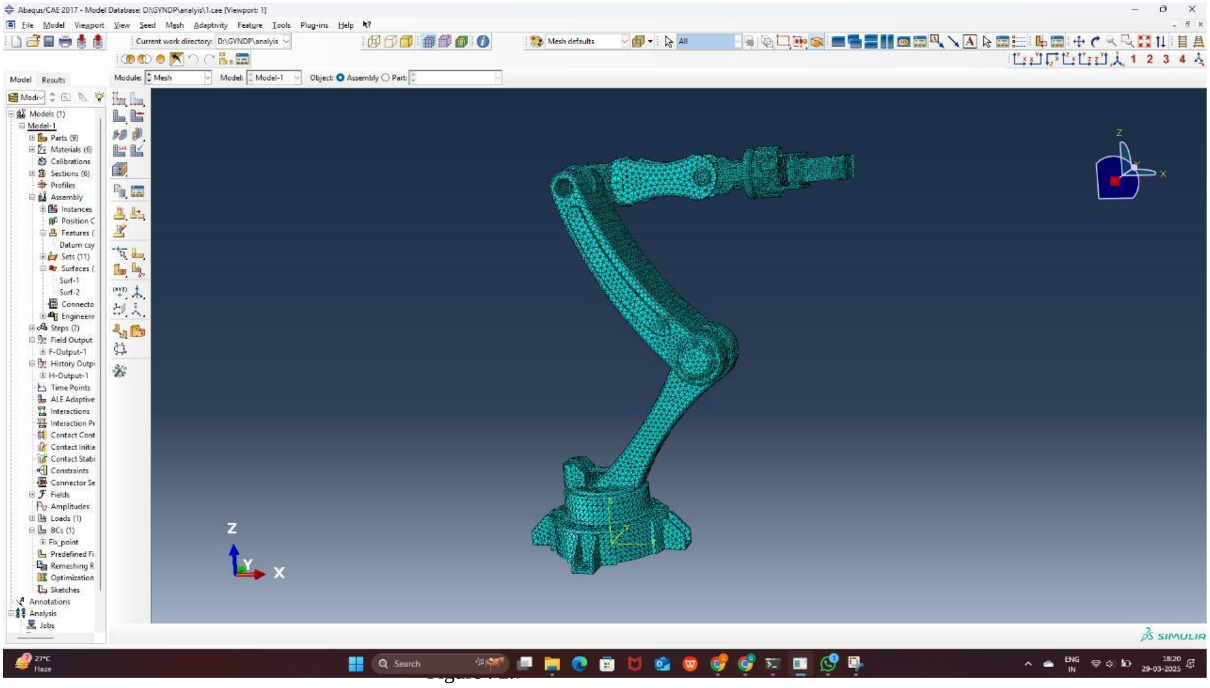



Figure : 2.7

### 3.4. Materials

**Structural steel** and **aluminum** are selected as the primary materials for the robotic arm due to their high strength and ability to withstand significant loads. The mechanical properties of these materials, which support their suitability for this application, are presented in **Tables 1 and 2**.

**Table 1: Properties of Structural Steel**

| PROPERTIES | VALUES |
|---|---|
| YOUNGS MODULUS | 210000 MPA |
| POISSON'S RATIO | 0.3 |
| DENSITY | 7.85e-9 g/mm^3 |

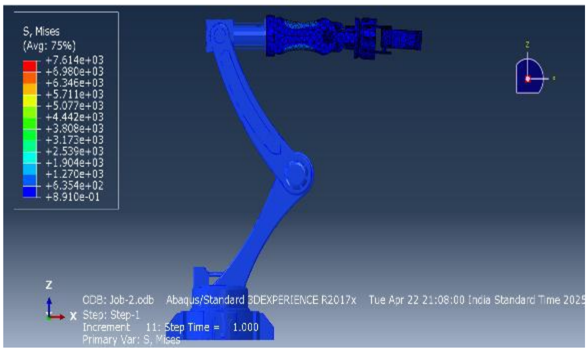
**Table 2: Properties of Aluminium Alloy 356**

| PROPERTIES | VALUES |
|---|---|
| YOUNGS MODULUS | 70000 MPA |
| POISSON'S RATIO | 0.33 |
| DENSITY | 2.68e-9 g/mm^3 |

## 4. Results and Discussion

The analysis involved applying varying loads to the gripper end of the robotic arm, using *Structural Steel* and *Aluminum Alloy 356* as the materials. The evaluation focused on determining *total deformation* and *von Mises stress* under four different loading conditions: *100 N*, *200 N*, *300 N*, and *400 N*. If the resulting stress exceeds the yield strength of the material, structural failure is likely to occur. The outcomes for the robotic arm constructed from Structural Steel are illustrated in *Figures 3.1–3.8*, while *Figures 4.1–4.8* present the corresponding results for the arm made from Aluminum Alloy 356.

STRUCTURAL STEEL



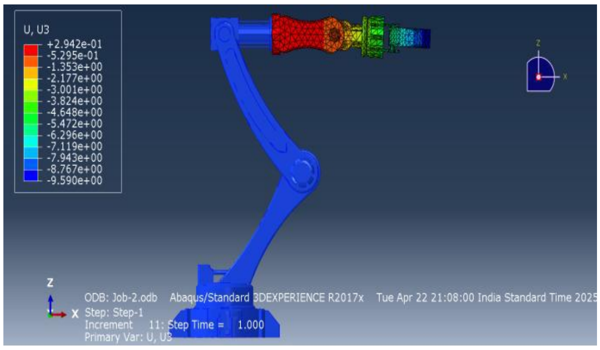
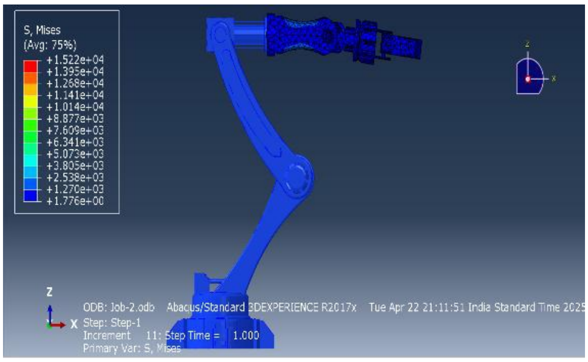




**Figure 3.1. Deformation at 100N** **Figure 3.2. Stress Analysis at 100N**



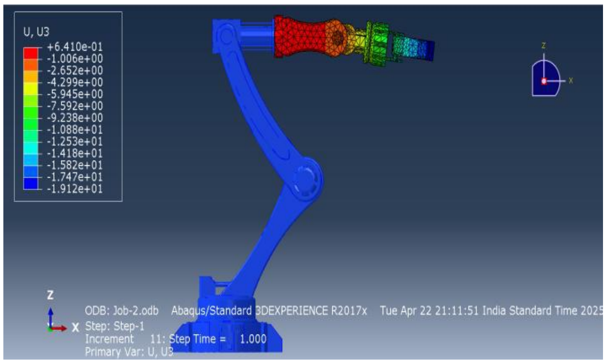
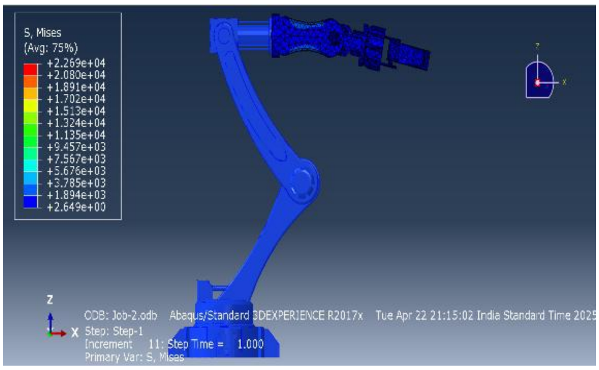




**Figure 3.3. Deformation at 200N** **Figure 3.4. Stress Analysis at 200N**



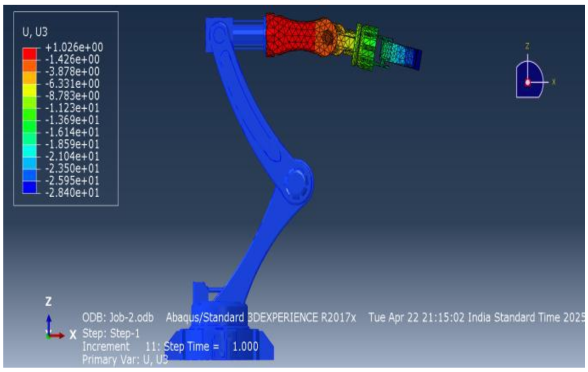
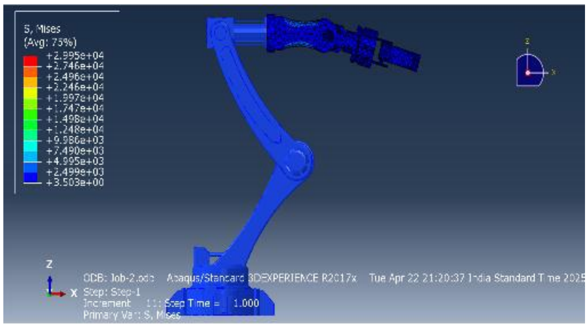




**Figure 3.5. Deformation at 300N** **Figure 3.6. Stress Analysis at 300N**



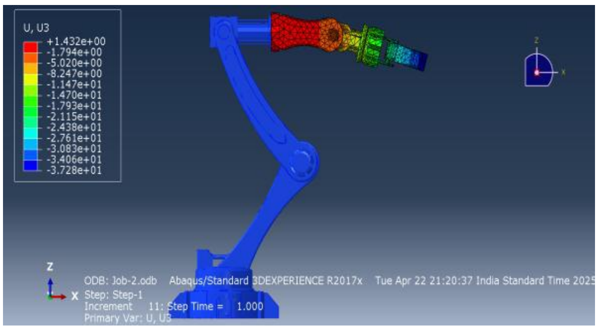




**Figure 3.7. Deformation at 400N** **Figure 3.8. Stress Analysis at 400N**

***ALUMINIUM ALLOY 356***

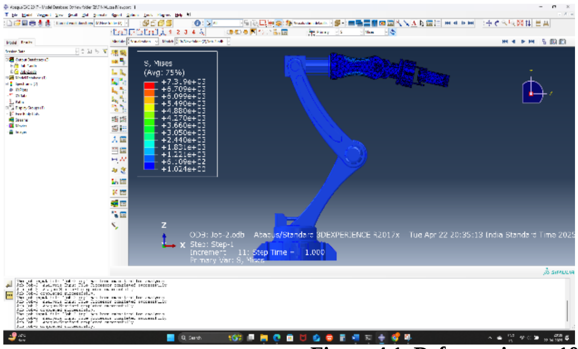


**Figure 4.1. Deformation at 100N**

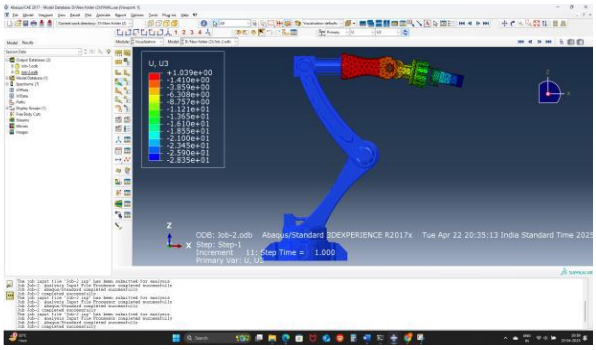


**Figure 4.2. Stress Analysis at 100N**

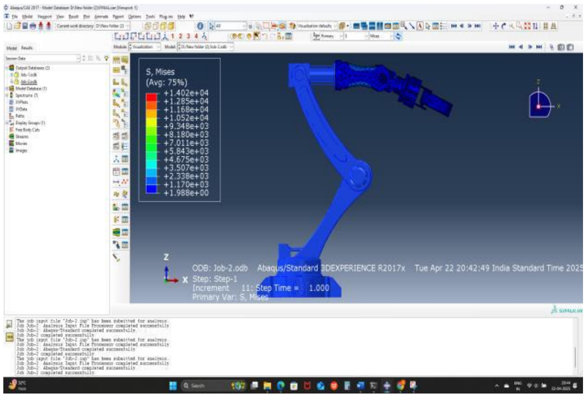


**Figure 4.3. Deformation at 200N**

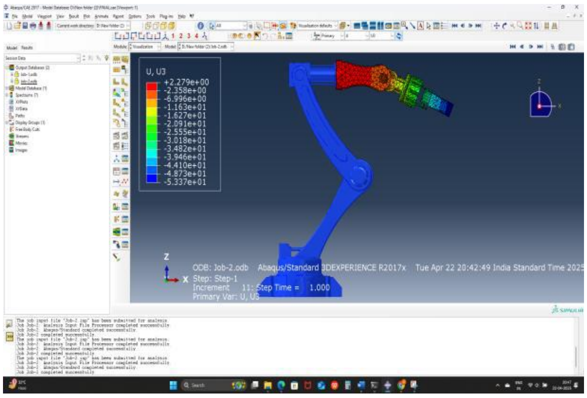


**Figure 4.4. Stress Analysis at 200N**

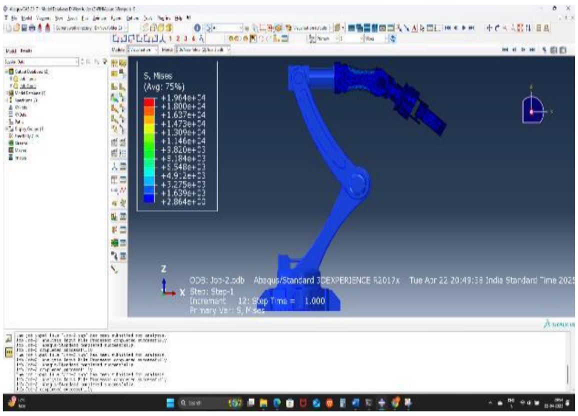


**Figure 4.5. Deformation at 300N**

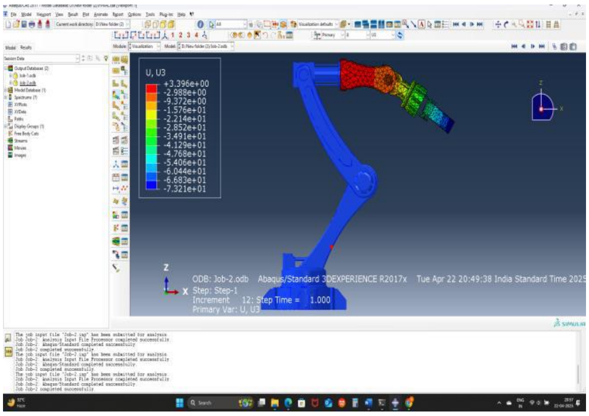


**Figure 4.6. Stress Analysis at 300N**

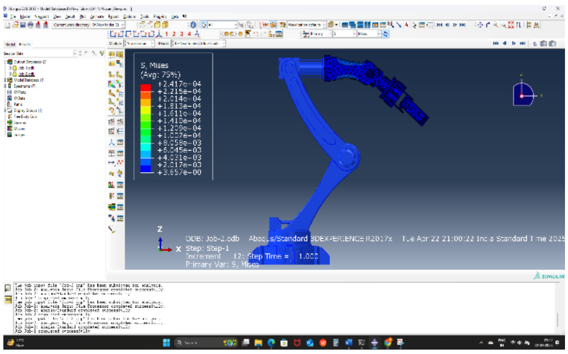


**Figure 4.7. Deformation at 400N**

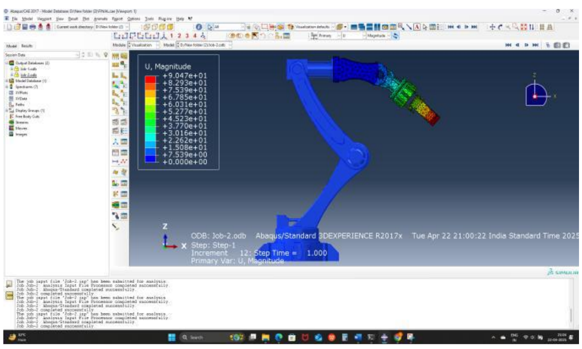


**Figure 4.8. Stress Analysis at 400N**

| S.NO | Force (N) | Max Equivalent Stress (MPa) | Max Deformation (mm) |
|---|---|---|---|
| 1) | 100 | 7614 | 0.2942 |

| | | | |
|---|---|---|---|
| 2) | 200 | 15,220 | 0.6410 |
| 3) | 300 | 22,690 | 1.0264 |
| 4) | 400 | 29950 | 1.4320 |

| S.NO | **Force** (N) | **Max Equivalent Stress (MPa)** | **Max Deformation (mm)** |
|---|---|---|---|
| 1) | 100 | 7,389 | 1.039 |
| 2) | 200 | 14,020 | 2.279 |
| 3) | 300 | 19,644 | 3.396 |
| 4) | 400 | 24,170 | 9.047 |

## 5. Conclusion

The creation of a versatile and cost-effective robotic hand that closely resembles the human hand has become essential in modern industries. A comprehensive model of the robotic arm was developed using CATIA, a 3D CAD software, and then subjected to structural analysis in ABAQUS. This robotic arm is designed for a variety of industrial tasks, such as material handling and assembly. The structural analysis validated that the arm meets all design specifications and can support varying payloads. Its potential use in hazardous environments can significantly improve safety while enhancing productivity. Future research could focus on simulating the arm's operation within a specific work environment.

### REFERENCES

[1] Shang, Y., & Kurt, E. C. (2010). A Geometric Approach for the Robotic Arm Kinematics with Hardware Design. Journal of Robotics, **10**.

[2] Rahman, A., Khan, A. H., Ahmed, T., & Md Sajjad, M. (2013). Design Analysis and Implementation of Robotic Arm – The Animator. American Journal of Engineering Research, **2**(10).

[3] Gautam, R., Gedam, A., Zade, A., & Mahawadiwar, A. (2017). Review on Development of Industrial Robotic Arm. International Research Journal of Engineering and Technology (IRJET), **4**(3).

[4] Omijeh, B. O., Uhunmwangho, R., & Ehikhamenle, M. (2014). Design Analysis of a Remote-Controlled "Pick and Place" Robotic Vehicle. International Journal of Engineering Research and Development, **10**.

[5] Katal, G., Gupta, S., & Kakkar, K. (2013). Design and Operation of Synchronized Robotic Arm. International Journal of Research in Engineering and Technology (IJRET), **2**(8).

[6] Gunasekaran, K. Design and Analysis of Articulated Inspection Arm of a Robot. International Journals for Trends.

[7] Ismail, A. Z. Introduction and Objective: Robotic Arm. Retrieved from Scribd

[8] Patil, C., Sachan, S., Singh, R. K., Ranjan, K., & Kumar, V. (2009). Self and Mutual Learning in Robotic Arm, Based on Cognitive Systems. Indian Institute of Technology, Kharagpur.

[9] Craig, J. J. (2005). Introduction to Robotics: Mechanics and Control (3rd ed.). Upper Saddle River, NJ: Pearson Prentice Hall.

[10] Angelo, J. A. (2007). Robotics: A Reference Guide to the New Technology. Westport, CT: Greenwood Press.

[11] Carlson, M., Donley, E., Graf, K., & Jones, T. (2013). Helping Hand: Senior Design Final Documentation. University of Central Florida, Orlando.

[12] Ghiet, A. M. A. Robot Arm Control with Arduino. Mechanical and Aeronautical Engineering. Retrieved from ResearchGate