# Finite Element Analysis of a Robotic Arm for Electronic Devices Transportation: Design and Simulation

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**Abstract.** Automation of various routine operations using the robotics arm in industrial automation is crucial for bridging innovative systems and production procedures, thereby speeding up the manufacturing process by reducing overall cycle times. In this work, Finite Element Method (FEM) is used to simulate a robotic arm for handling electronic printers to foster their transportation. The analysis considers different loads and materials which include AISI 304, cast carbon steel, aluminium alloy 1060, malleable cast iron and AISI 1020. The effects of discrete particulate mechanical properties, concerning material, load zone and design configuration parameters were revealed. The remarkable result of these simulations shows displacement, tensile and compressive strain distribution values as a conclusion of the better capacity for anticipated lightweight operation using aluminium alloy 1060 robotic arm transporting device. In addition, the current simulations give a profound picture of how materials are selected to maximize the operational process.

**Keywords:** Finite Element Analysis, Electronic Devices Transportation, Robotic Arm

## 1 Introduction

Robotic arms are used in several different industries, from manufacturing, healthcare and logistics to environmental science. The robotic arm is capable of doing the replication tasks with accuracy and speed, these machines are extremely helpful in increasing productivity while reducing the potential for human error. For this application, a fixed-based robotic arm with a 3 jointed arm which has two joints more for vertical and horizontal movement is employed, so that it can be obediently navigated and manipulated [1]. The versatility of manipulating multiple degrees of freedom makes articulated robotic arm design an ideal solution for a variety of settings. This flexibility is important for the challenges of different tasks in different industries. The investigation conducted delves into the importance of joint modification in improving motion capabilities [2]. Dynamic Finite Element Analysis (FEA) is essential to the design and verification cycle, which provides a more complete view of robotic arm performance under different loading conditions depending on the availability of tasks in printer transport [3]. FEA is a powerful tool to predict the performance of complex mechanical assemblies that involve the analysis phases for troubleshooting and optimization.

Research has been carried out on dynamic analysis using FEA techniques. The modelling and simulation of a six-axis robotic arm used to perform pick-and-place operations that constitute a dynamic system also presented the need for an accurate model and simulation to predict performance metrics and optimize controlled parameters [4]. It was also used to investigate the dynamic behaviour of a robotic arm for material handling applications, aimed at determining its structural capacity and load points leading to failures under various loading conditions [5]. The results have helped in better designing and safe operational procedures in industrial sectors. Previous studies have improved the understanding of the dynamic analysis of robotic arms, and in contrast, still lacking research on electronic device handling. Therefore, this research aims to conduct a dynamic finite element analysis of a robotic arm for printer transportation. The arm design, simulation and operation optimization will be implemented aiming at an efficient operation of the arm which shall serve as leverage to better develop future designs of robotic arms for electronic device transportation.

## 2 Material and Methods

### 2.1. Materials

In this basic stress analysis, the design process and material selection for the robotic arm were carefully examined, focusing on mechanical behaviour. The study investigates several materials, including AISI 304, cast carbon steel, aluminium alloy 1060, malleable cast iron, and AISI 1020, as detailed in Table 1. The primary objective is to evaluate how varying loads impact the arm's performance. Malleable cast iron serves as a baseline material for comparison, while the arm configuration remains consistent across all scenarios.

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**Table 1.** Comparison of mechanical properties between AISI 304, cast carbon steel, aluminium alloy 1060, malleable cast iron, and AISI 1020 [6].

| **Materials** | **AISI 304** | **Cast carbon steel** | **Aluminium alloy 1060** | **Malleable cast iron** | **AISI 1020** |
|---|---|---|---|---|---|
| Tensile Strength ($\times 10^8$ $Nm^{-2}$) | 5.170 | 4.825 | 0.689 | 4.136 | 4.205 |
| Elastic Modulus ($\times 10^{11}$ $Nm^{-2}$) | 1.9 | 2.0 | 0.7 | 1.9 | 2.1 |
| Poison's ratio | 0.29 | 0.32 | 0.33 | 0.27 | 0.29 |
| Mass density ($kg/m^3$) | 8,000 | 7,800 | 2,700 | 7,300 | 7,900 |
| Shear Modulus ($\times 10$ $Nm^{-2}$) | 7.5 | 7.6 | 2.7 | 8.6 | 7.7 |
| Yield Strength ($\times 10^8$ $Nm^{-2}$) | 2.068 | 2.481 | 0.227 | 2.757 | 3.515 |
| Thermal Expansion ($\times 10^{-5} K^{-1}$) | 1.8 | 1.2 | 2.4 | 1.2 | 1.5 |

## 2.2 Design and Static Load Analysis

The robotic arm's design, tailored to the electronic printer size, encompasses precise dimensions as displayed in Figure 1 with a depth thickness of 56 cm. Using the 3D design created in SolidWorks and a static printer load of 25 kg, five simulations for the materials AISI 304, cast carbon steel, aluminium alloy 1060, malleable cast iron, and AISI 1020 were conducted to obtain their mechanical properties through FEA analysis in SolidWorks. These measurements, and adaptability within the specified parameters, reflect the careful alignment with the electronic printer's specifications.

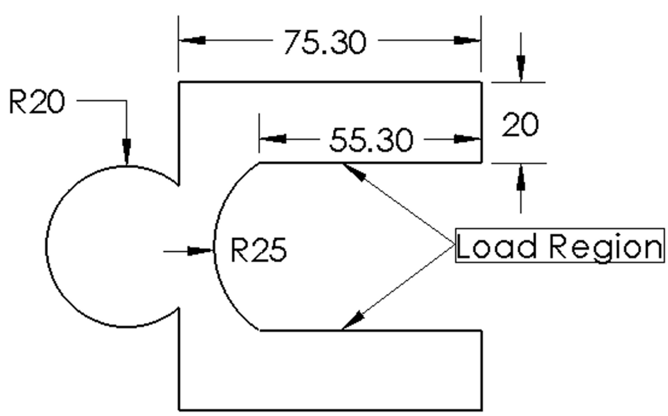


**Fig. 1.** Design of robotic arm (unit cm).

In the finite element analysis of the robotic arm designed for carrying a printer, printer loads may need a thorough analysis as they can differ from model to configuration [7]. It is important to analyze the various loads as they reveal structural integrity and capabilities mounted on the robotic arm under different conditions. The load area is further defined into regions to study the arm handling the weights of 25kg, examining its mechanical adaptability and performance on dissimilar operational demands. The study aims to evaluate the distribution of strain, stress, and deformation patterns of the arm by applying a range of printer loading in the respective region.

In contrast, unstructured meshing with irregularly shaped elements and size variations has been used to promote greater flexibility which is essential for accurately representing intricate and complex geometries [8]. Adaptive meshing brings in dynamism and fine tunes by refining or coarsening the mesh depending on certain criteria to optimize the computational resources and improve the accurate impact at specific areas [9]. Hence the robot arm structure was modelled with unstructured mesh and a total of 12,879 elements was preferred as shown in Table 2.

**Table 2.** Structure meshing setup.

| | |
|---|---|
| Study name | Static 2(-Default-) |
| Mesh type | Solid Mesh |
| Mesher used | Standard mesh |
| Automatic Transition | Off |
| Include Mesh Auto Loops | Off |
| Jacobian points for High-quality mesh | 16 points |
| Element size | 23.7667 mm |
| Tolerance | 1.18833 mm |
| Mesh quality | High |
| Total nodes | 21595 |
| Total elements | 12879 |

## 3 Results and Discussion

The focus shifts to the results obtained from the comprehensive simulations conducted in methodology. The primary goal is to evaluate the suitability of five different materials AISI 304, cast carbon steel, aluminium alloy 1060, malleable cast iron, and AISI 1020 for the robotic arm based on their performance in mechanical behaviour analyses. This finding delves into stress, strain, and displacement analyses to identify the most suitable material that ensures optimal functionality and durability as displayed in Figure 3. AISI 304 stands out with a high tensile strength of $5.17\times10^{8}$ $Nm^{-2}$, excellent elastic modulus of $1.9\times10^{11}$ $Nm^{-2}$, and a relatively low thermal expansion coefficient of $1.8\times10^{-5}$ $K^{-1}$. Cast carbon steel exhibits commendable tensile and yield strength, making it a robust choice for heavy-duty applications. Aluminium alloy 1060 offers a lightweight option with a favourable strength-to-weight ratio, while malleable cast iron provides high tensile strength and good impact resistance. AISI 1020, a low-carbon steel variant, is notable for its good machinability and weldability.

The stress-strain (maximum value) analysis reveals distinctive performance characteristics among the materials considered for the robotic arm. Malleable cast iron emerges as the top contender, boasting the highest stress value ($1.694\times10^{3}$ $Nm^{-2}$) and demonstrating exceptional strength, making it an ideal choice for applications demanding robust load-bearing capabilities. Following closely, AISI 304 and AISI 1020 exhibit comparable strength, with stress values of 1.653×10$^3$ Nm$^{-2}$ reflecting their suitability for rigorous tasks. Cast carbon steel, ranking fourth in stress (1.591×10$^3$ Nm$^{-2}$), showcases substantial strength but falls slightly behind AISI 304 and AISI 1020. Notably, aluminium alloy 1060 exhibits the lowest stress value (1.570×10$^3$ Nm$^{-2}$), highlighting its suitability for scenarios prioritizing lightweight construction over maximum strength.

a) b) c)

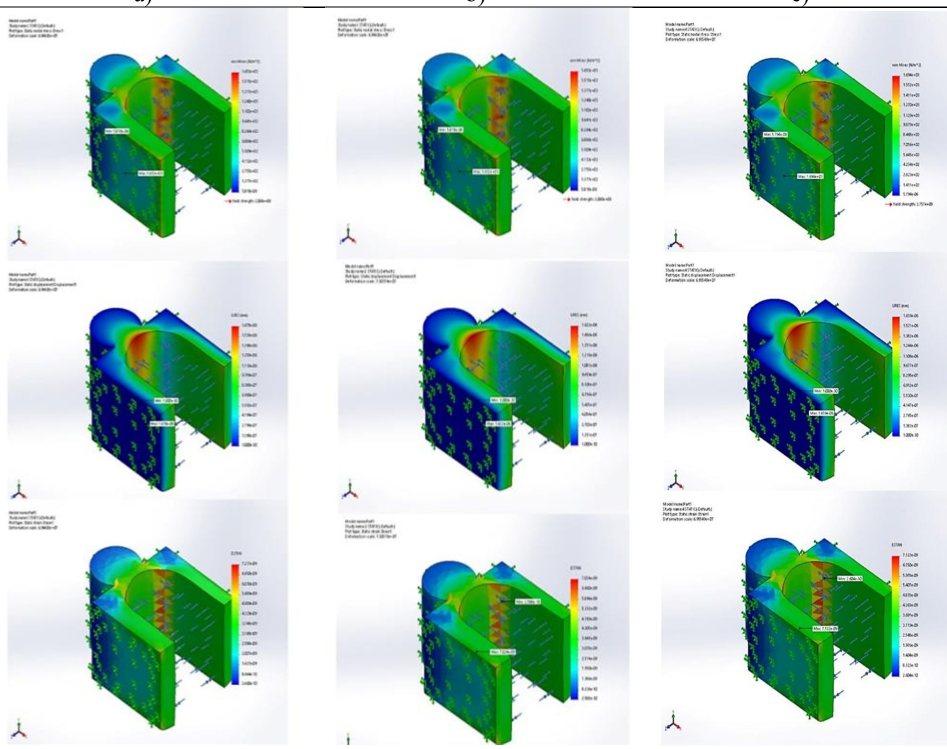

**Fig. 3.** Stress, Displacement and Strain of a) AISI 304 b) Cast carbon steel c) Aluminium alloy 1060.

Examining the displacement maximum values provides insights into the materials' deformation characteristics as shown in Figures 3 and 4, respectively. Aluminium alloy 1060 emerges as the leading performer, showcasing the highest displacement value of 4.737×10$^{-6}$ mm. Following closely, AISI 304 secures the second position, with a displacement value of 1.678×10$^{-6}$ mm, highlighting its ability to undergo controlled deformation. Notably, malleable cast iron demonstrates a displacement value very close to AISI 304 [10], securing the third position. Cast carbon steel follows suit in the fourth position, while AISI 1020 takes the fifth spot with the lowest displacement value of 1.594×10$^{-6}$ mm. This ranking suggests that aluminium alloy 1060 is the most deformable among the materials, making it suitable for applications where controlled flexibility is essential. AISI 304, with its moderate displacement, strikes a balance between flexibility and rigidity. Malleable cast iron, cast carbon steel, and AISI 1020 exhibit varying degrees of deformation resistance, aligning with their mechanical properties and intended applications.

| c) | d) |
|---|---|

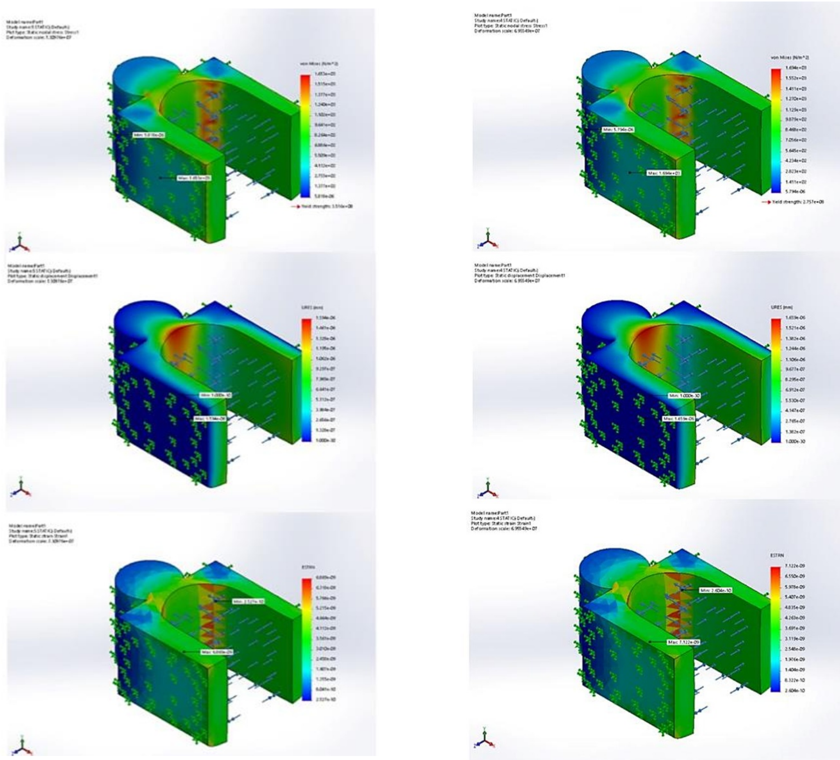

**Fig. 4.** Stress, Displacement and Strain of c) Malleable cast iron d) AISI 1020.

Upon analysing the stress-strain (minimum value) in Table 3 and the corresponding data, a nuanced perspective on the materials' elastic behavior and recovery from deformation emerges. AISI 304 claims the top position with the highest stress recovery, evidenced by a stress value of $1.653 \times 10^{3}$ $Nm^{-2}$ and minimal permanent deformation, as indicated by a strain value of $2.660 \times 10^{-10}$. AISI 1020 closely follows suit, demonstrating an impressive stress recovery of $1.653 \times 10^{3}$ $Nm^{-2}$ and a strain value of $2.527 \times 10^{-10}$, aligning with its resilient characteristics. Cast Carbon Steel secures the third position, showcasing notable stress recovery ($1.591 \times 10^{3}$ $Nm^{-2}$) and substantial elastic response ($2.588 \times 10^{-10}$). Malleable cast iron, although slightly behind in stress recovery, exhibits commendable elastic behavior, with a stress value of $1.694 \times 10^{3}$ $Nm^{-2}$ and a strain value of $2.604 \times 10^{-10}$. On the other hand, aluminium alloy 1060 reveals the lowest stress recovery ($1.570 \times 10^{3}$ $Nm^{-2}$) and an extended elastic response ($7.564 \times 10^{-10}$), indicating a higher susceptibility to permanent deformation. In summary, AISI 304 and AISI 1020 shine in stress recovery, making them preferred choices for applications where minimal permanent deformation is crucial [11]. Cast Carbon Steel and Malleable cast iron also display commendable elastic behaviour. However, aluminium alloy 1060, with its lower stress recovery, is more prone to permanent deformation, aligning with its lightweight and less rigid nature.

**Table 3.** Stress, displacement and strain of AISI304, Cast carbon steel, Aluminium alloy 1060, Malleable cast iron and AISI 1020 maximum and minimum value.

| **Material** | **Stress ($Nm^{-2}$)** | | **Displacement (mm)** | **Strain** | |
|---|---|---|---|---|---|
| | **Maximum value** ($\times 10^{3}$) | **Minimum value** ($\times 10^{-6}$) | **Maximum value** ($\times 10^{-6}$) | **Maximum value** ($\times 10^{-9}$) | **Minimum value** ($\times 10^{-10}$) |
| AISI 304 | 1.653 | 5.818 | 1.678 | 7.231 | 2.660 |
| Cast carbon steel | 1.591 | 5.808 | 1.622 | 7.024 | 2.588 |
| Aluminium alloy 1060 | 1.570 | 5.787 | 4.737 | 20.531 | 7.564 |
| Malleable cast iron | 1.694 | 5.794 | 1.659 | 7.122 | 2.604 |
| AISI 1020 | 1.653 | 5.818 | 1.594 | 6.869 | 2.527 |

Stress analysis revealed the malleable cast iron perceived maximum stress values, signifying that it is an appropriate material to bear heavy loads. However, the maximum values of the displacement were defined to support that aluminium alloy 1060 presented higher deformability, which is required for applications with a wider range of controlled flexibility. AISI 304 always rose as a better option regarding both stress and displacements, indicating a balanced performance, enveloping many robotic arm applications. AISI 1020 on the other hand was not as performing as AISI 304, but it presented a competitive behavior. Treated materials including cast carbon steel and aluminium alloy 1060 had low stress and were highly deformable. Due to its robustness and the comprehensive evaluation revealed minimum stress, strain and displacement, malleable cast iron is considered the optimum choice for the robotic arm while aluminium alloy 1060 is also one of the high-quality contenders dedicated to flexibility applications.

## 4 Conclusion

This paper concludes that the robotic arm will not experience any material yielding due to the tension developed during loading, resulting in minimal strain and only a limited amount of material displacement. The best performance in terms of stress recovery was shown by AISI 304 and AISI 1020 making them versatile choices, whereas such motivating results from the malleable cast iron as the most analogous material for robust load-bearing capabilities, and aluminium alloy 1060 presented itself somehow for lightweight application. Load analysis showed that malleable cast iron exhibited stable and reliable mechanical properties across loads applied. The behaviour of tested materials, as of stress-strain and displacement analysis, has given insight into determining the appropriate material applications. The results of this study will help manufacturers, especially in the robotics arm production sector in selecting materials, enhancing production efficiency, automating tasks and ensuring greater reliability that assist in operational efficiency while still balancing the need for maximum safety.

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