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ADVANCEMENTS IN FORKLIFT TECHNOLOGY: ENHANCING INDUSTRIAL EFFICIENCY AND SAFETY THROUGH DIVERSE MATERIALS APPLICATIONS

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Abstract- A forklift is a versatile industrial vehicle used for lifting, transporting, and stacking materials. Available in electric, diesel, and gas-powered models, forklifts enhance efficiency and reduce injury risks in various environments. Electric models are ideal for indoor use, while gas-powered ones excel outdoors. Modern advancements include remote control capabilities for increased safety and precision. Using materials like mild steel ensures minimal fork deformation. Forklifts can lift to 500 kg at an ITA rating of 990.6 mm and 1016 mm. Future developments will focus on ergonomic design, lightweight materials, safety features, hybrid models, and smart technology integration.

Keywords: Forklift, Different Design, Different Materials, Weight, Fork

1. INTRODUCTION

A forklift is a versatile and powerful industrial vehicle essential for lifting, transporting, and stacking materials over short distances. Resembling a small truck, it is equipped with two metal forks at the front designed to handle heavy loads with ease. Forklifts are widely used in warehouses, construction sites, and manufacturing facilities, where they significantly improve efficiency and reduce the risk of injury. They come in various types, including electric, diesel, and gas-powered models, each tailored to specific environments and applications. Electric forklifts are ideal for indoor use due to their emission-free operation, while gasoline and propane forklifts offer greater speed and power for outdoor or heavy-duty tasks, albeit with higher maintenance and fuel costs. Rough terrain forklifts, built for construction sites and uneven surfaces, have the highest lifting capacities and robust tires to handle challenging conditions. The advent of forklifts has revolutionized material handling, enabling a single operator to move thousands of pounds safely and efficiently. Modern advancements have even introduced remote control capabilities, allowing operators to maneuver forklifts with greater precision and visibility, further enhancing safety and operational accuracy. Popular types of forklifts include warehouse forklifts, side loaders, counterbalance forklifts, telehandlers, and pallet jacks, among others, each serving unique purposes in diverse industrial applications.

1.1. Advantages of Forklift:

Forklifts offer several advantages in various industries, particularly in warehousing, manufacturing, construction, and logistics. Here are some of the key benefits of using forklifts:

a. Increased Efficiency and Productivity- Forklifts can move heavy loads quickly and efficiently, significantly speeding up the process of loading and unloading materials. Modern forklifts are equipped with advanced controls and navigation systems, allowing for precise handling of goods.

b. Versatility- There are many types of forklifts designed for specific tasks, such as counterbalance forklifts, reach trucks, pallet jacks, and rough terrain forklifts. Forklifts can be fitted with various attachments (e.g., clamps, rotators, side shifters) to handle different types of loads.

c. Safety- Forklifts reduce the need for manual lifting, lowering the risk of injuries associated with heavy lifting and repetitive strain. They are designed to safely lift and transport heavy loads, with features such as counterbalancing to prevent tipping.

d. Cost-Effective- By increasing the speed and efficiency of material handling, forklifts can help reduce labor costs. High-quality forklifts are durable and can last many years with proper maintenance, offering a good return on investment.

e. Handling Heavy Loads- Forklifts can handle very heavy loads, with some models capable of lifting several tons. They allow for the efficient stacking of goods, maximizing warehouse space.

f. Improved Ergonomics- Modern forklifts are designed with operator comfort in mind, featuring ergonomic seats, controls, and easy-to-read displays. They minimize the physical strain on workers, contributing to a healthier work environment.

g. Flexibility in Operations- Forklifts are suitable for both indoor and outdoor applications, with specific models designed to navigate different terrains. They can move easily through narrow aisles and tight spaces, enhancing their usability in confined areas.

h. Adaptability to Different Work Environments- There are specialized forklifts for hazardous environments, such as explosion-proof models for use in chemical plants or other volatile settings. Many forklifts are built to operate in various weather conditions, ensuring continuous operation regardless of the environment.

i. Technology Integration- Some modern forklifts come with automated features and AI integration, allowing for semi-autonomous or fully autonomous operation. Advanced forklifts can be equipped with telematics systems to monitor performance, and maintenance needs, and optimize fleet management.

j. Environmentally Friendly Options- Electric models produce zero emissions, making them suitable for indoor use and environmentally conscious operations. Newer models are designed to be more energy-efficient, reducing overall energy consumption and operational costs.

By leveraging these advantages, businesses can improve their material handling processes, enhance safety, and boost overall productivity.

1.2. Disadvantages of Forklift:

While forklifts offer numerous advantages, they also come with certain disadvantages and challenges. Here are some of the key disadvantages associated with forklift use:

a. Safety Risks- Forklifts can pose significant safety hazards if not operated correctly, including the risk of tipping over, collisions, and injuries to operators or bystanders. Mistakes by operators, such as improper loading, excessive speed, or lack of awareness, can lead to accidents.

b. Operational Costs- The cost of purchasing a forklift can be high, especially for advanced models with additional features. Regular maintenance and repair costs can add up, particularly for older or heavily used forklifts. Depending on the type of forklift (e.g., diesel, propane, electric), fuel and energy costs can be significant.

c. Limited Mobility- Forklifts may have difficulty accessing narrow or confined spaces, limiting their usability in some environments. Not all forklifts are suitable for all types of terrain. For example, standard forklifts may struggle on rough or uneven surfaces, requiring specialized models.

d. Environmental Concerns- Diesel and propane forklifts produce emissions that can be harmful to the environment and indoor air quality. Some forklifts can be noisy, contributing to noise pollution in the workplace.

e. Training Requirements- Proper training is essential for safe and efficient forklift operation, which can be time-consuming and costly. Operators may need to obtain certifications, depending on local regulations, adding to the administrative burden.

f. Storage and Space- Forklifts themselves require storage space when not in use, which can be a challenge in smaller facilities. Warehouses and storage areas must have aisles wide enough to accommodate forklift operation, potentially reducing storage density.

g. Wear and Tear- Forklifts are subject to significant wear and tear, especially tires, forks, and hydraulic systems, which can lead to frequent repairs. Forklifts depreciate over time, reducing their resale value.

h. Load Limitations- Each forklift has a specific weight capacity, and exceeding this limit can be dangerous and lead to equipment failure. Improperly balanced or unstable loads can cause tipping or dropping of materials.

i. Operational Limitations- Electric forklifts have limited battery life and require downtime for recharging, which can affect productivity. Battery-operated forklifts can have reduced performance in cold environments.

j. Insurance and Liability- The potential for accidents and damage can lead to high insurance premiums for forklift operations. Companies can face significant liability issues in the event of forklift-related accidents, injuries, or property damage.

Understanding these disadvantages can help businesses make informed decisions about forklift use and implement measures to mitigate these challenges. Proper training, regular maintenance, and adherence to safety protocols are essential for minimizing risks and maximizing the benefits of forklifts.

2. LITERATURE REVIEW

Khebude Karan N [1] examines the design and static structural analysis of a forklift fork using ANSYS R16.0. By comparing theoretical calculations with ANSYS results, the study highlights how using mild steel, with its high specific stiffness and strength, enhances fork performance by reducing deformation and bending under load. Mechanical forklifts have revolutionized the mechanical industry by enabling efficient material handling. Krunal R. Dhivar [2] allows a single operator to move thousands of pounds, enhancing safety and productivity. This prototype features remote technology for improved visibility and precision, increasing operator safety and accuracy. V. R. Gandhewar et al. [3] investigate that a forklift truck is a powered industrial vehicle for lifting and transporting materials. It operates on battery power, utilizing a lead screw mechanism for lifting. Our "Battery Operated Forklift" project aims to create a pollution-free, efficient forklift. By using battery power and a lead screw, the design enhances safety by allowing remote operation, which improves operator visibility and reduces human errors. This approach increases productivity and efficiency while minimizing environmental impact. Suryavanshi Amol V [4] investigated traditional forklifts have significant environmental impacts, such as carbon dioxide emissions and hydraulic fluid leaks. Integrating an electric system into a forklift makes it electrically powered, reducing the environmental impact of fuel-based forklifts. This technology also lessens human effort and errors, making it both user- and environmentally friendly.

Additionally, electric forklifts are highly affordable and cost-effective. Yadav et al. [5] describe a forklift powered by an electric motor using rechargeable batteries, aiming to design an electrically powered forklift for material handling in industrial warehouses and workshops. Traditional forklifts, operating on IC engines and hydraulic systems, cause environmental issues like carbon dioxide emissions and hydraulic fluid leaks. Our electric forklift addresses these problems, capable of lifting to 1 ton and elevating materials up to 8 feet, offering a cleaner and more efficient solution. Sudhakar et al. [6] designed for industrial applications, offers efficient mobility from one location to another. This system ensures the timely completion of tasks such as transporting goods, adhering to scheduled operations, and reducing cycle times. The carrier system optimizes productivity by minimizing the handling, fixing, and transit time traditionally wasted on moving goods. The saved time can be reallocated to enhance production processes, improving overall operational efficiency within the industrial environment. Panara et al. [7] utilize these devices, the efficiency of material handling is significantly improved, reducing manual labor and minimizing the time and effort involved in moving heavy loads. This enhances operational workflow and contributes to a safer and more organized work environment.

3. OBJECTIVE

This research aims to optimize the design of a manual forklift with a 500 kg load capacity by conducting a structural analysis using ANSYS software. The study evaluates four different materials: structural steel, gray cast iron, stainless steel, and aluminum alloy. Key parameters analyzed include directional deformation maximum, normal elastic strain, shear elastic strain, normal stress, and shear stress. The objective is to identify the most suitable material for the forklift structure by comparing these parameters, ensuring optimal performance and safety. The findings will guide the material selection process for improved durability and efficiency in manual forklift design.

4. WORKING PRINCIPLE OF MANUAL FORKLIFT

The manual forklift (Figure 1) operates on a simple yet effective principle, leveraging mechanical advantage to manually lift and transport heavy loads. Consisting of a sturdy frame with two forks extending from the front, the manual forklift is maneuvered by an operator who manually pumps a lever or rotates a handle to raise or lower the forks. This action engages a hydraulic system or a series of gears and pulleys, amplifying the force applied by the operator to lift the load. The forks slide beneath the load, which is then elevated by the lifting mechanism. The operator can then steer the forklift by maneuvering the handle or steering wheel, allowing precise load placement at its destination. The simplicity of its design enables the manual forklift to be versatile and easy to operate, making it suitable for various applications in warehouses, factories, and other industrial settings where heavy lifting is required.

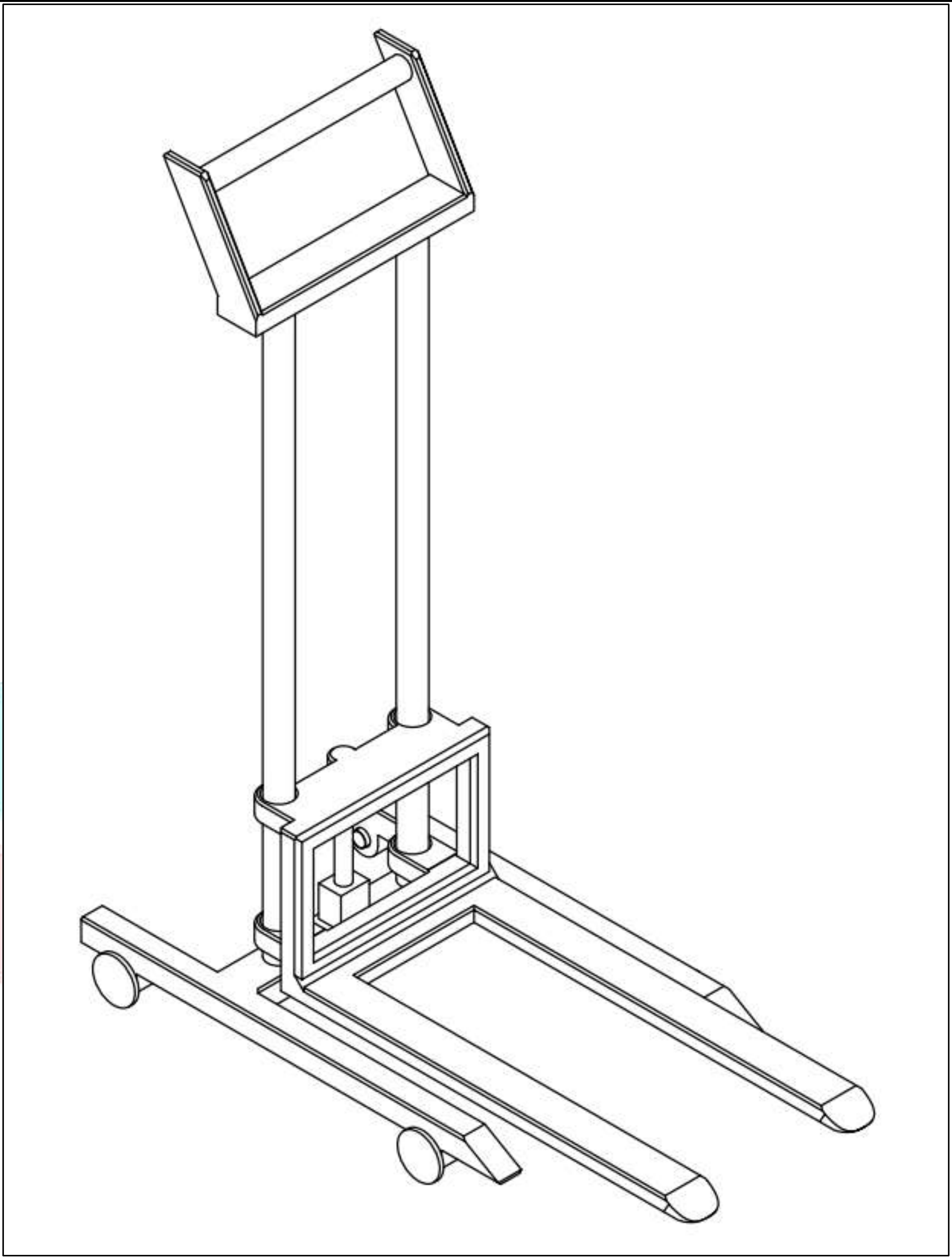

Figure 1: 2D Schematic Diagram of Manual Forklift

5. BASIC METHOD

Manual forklifts, or hand pallet jacks, are used to lift and move pallets within warehouses or other facilities. To understand the basic calculations involved in operating a manual forklift, we need to consider the following:

a. Force Required to Lift a Load

b. Force Required to Move a Load Horizontally

c. Load Distribution and Stability

a. Force Required to Lift a Load

To lift a load using a manual forklift, you need to overcome the gravitational force acting on the load. This can be calculated using the formula:

$F_{lift} = m.g$

Where:

F_{lift} is the force required to lift the load (in Newtons, N).

m is the mass of the load (in kilograms, kg).

g is the acceleration due to gravity (approx. 9.81 m/s^2).

b. Force Required to Move a Load Horizontally

To move a load horizontally, you need to overcome the rolling resistance. The force required can be calculated using:

$F_{horizontal} = \mu.m.g$

Where:

$F_{horizontal}$ is the force required to move the load horizontally (in Newtons, N).

μ is the coefficient of rolling resistance (dimensionless). For a typical hand pallet jack, this ranges from 0.01 to 0.05.

m is the mass of the load (in kilograms, kg).

g is the acceleration due to gravity (approx. 9.81 m/s^2).

c. Load Distribution and Stability

For stability and to avoid tipping over, ensure the load is evenly distributed and the center of gravity is low. The moment (torque) caused by the load should be less than the moment that would cause the forklift to tip.

For example, assume you have a load of 500 kg on a manual forklift. Let's calculate the force required to lift and move this load.

Force to Lift the Load-

m = 500 kg

g = 9.81 m/s^2

F_{lift} = 500 kg × 9.81 m/s^2

F_{lift} = 4905 N

Force to Move the Load Horizontally-

Assume μ = 0.02 (average rolling resistance for a manual pallet jack on a smooth surface):

$F_{horizontal} = 0.02 \times 500 \text{ kg} \times 9.81 \text{ m/s}^2$

$F_{horizontal}$ = 98.1 N

So, we need 4905 N of force to lift the load vertically and 98.1 N of force to move it horizontally on a smooth surface.

6. STRUCTURAL ANALYSIS PROCEDURE

Here, we give the full procedure of structural analysis using ANSYS software.

6.1 Material Properties Compositions

a. Fork Material: Structural Steel

Chemical Composition:

Carbon (C) = 0.25% max

Manganese (Mn) = 0.80% - 1.20%

Phosphorus (P) = 0.04% max

Sulfur (S) = 0.05% max

Silicon (Si) = 0.40% max

Copper (Cu) = 0.20% min (if specified for corrosion resistance)

Mechanical Properties:

Tensile Yield Strength (S_{yt}) = 250 MPa

Ultimate Tensile Strength (S_{ut}) = 400 - 550 MPa

Young's Modulus (E) = 200 GPa

Poisson's Ratio (μ) = 0.26

Density (ρ) = 7850 kg/m³

b. Fork Material: Gray Cast Iron

Chemical Composition:

Carbon (C) = 3.1% – 3.4%

Silicon (Si) = 1.8% – 2.3%

Manganese (Mn) = 0.5% – 0.7%

Phosphorus (P) = 0.15% max

Sulfur (S) = 0.15% max

Iron (Fe) = Balance

Mechanical Properties:

Tensile Strength (S_{ut}) = 276 MPa

Compressive Strength (S_{yc}) = Typically higher than tensile strength, about 3-4 times the tensile strength

Young's Modulus (E) = 100 – 140 GPa (100,000 – 140,000 MPa)

Poisson's Ratio (μ) = 0.26

Density (ρ) = 6800 – 7200 kg/m³

c. Fork Material: Stainless Steel

Chemical Composition:

Carbon (C) = 0.08% max

Manganese (Mn) = 2.00% max

Phosphorus (P) = 0.045% max

Sulfur (S) = 0.030% max

Silicon (Si) = 0.75% max

Chromium (Cr) = 18.00% – 20.00%

Nickel (Ni) = 8.00% – 10.50%

Nitrogen (N) = 0.10% max

Iron (Fe) = Balance

Mechanical Properties:

Tensile Yield Strength (S_{yt}) = 205 MPa

Ultimate Tensile Strength (S_{ut}) = 515 MPa

Young's Modulus (E) = 193 GPa (193,000 MPa)

Poisson's Ratio (μ) = 0.30

Density (ρ) = 8000 kg/m³

d. Fork Material: Aluminum Alloy

Chemical Composition:

Aluminum (Al) = 95.8% – 98.6%

Magnesium (Mg) = 0.8% – 1.2%

Silicon (Si) = 0.4% – 0.8%

Iron (Fe) = 0.0% – 0.7%

Copper (Cu) = 0.15% – 0.40%

Chromium (Cr) = 0.04% – 0.35%

Zinc (Zn) = 0.0% – 0.25%

Titanium (Ti) = 0.0% – 0.15%

Manganese (Mn) = 0.0% – 0.15%

Other = Each 0.05% max, Total 0.15% max

Mechanical Properties:

Tensile Yield Strength (S_{yt}) = 276 MPa

Ultimate Tensile Strength (S_{ut}) = 310 MPa

Compressive Yield Strength (S_{yc}) = Approximately 276 MPa

Young's Modulus (E) = 69 GPa (69,000 MPa)

Poisson's Ratio (μ) = 0.33

Density (ρ) = 2700 kg/m^3

6.2 Steps for Structural Analysis Using ANSYS

a. Open ANSYS and Select Static Structural Analysis

Open the ANSYS Workbench.

Drag and drop the "Static Structural" module into the Project Schematic.

b. Enter the Engineering Data of the Material (Mild Steel)

Double-click on "Engineering Data" in the Project Schematic.

Add a new material if not already available.

Enter the material properties.

c. Select Geometry and Import the Model

Double-click on "Geometry" in the Project Schematic.

Import your model in .stp or .igs format:

Go to File > Import External Geometry File.

Select your .stp or .igs file and click Open.

Generate the geometry:

Click on "Generate" to confirm the geometry import.

d. Set Up the Mesh

Double-click on "Model" to open the Mechanical module.

In the Mechanical module, select "Mesh" from the Outline tree.

Apply face sizing and set the mesh method:

Right-click on "Mesh" > Insert > Sizing.

Select the faces where you want to apply sizing and specify the element size.

Set the method to "Path Conforming".

e. Apply Boundary Conditions

Apply fixed support:

Right-click on "Static Structural" > Insert > Fixed Support.

Select the faces or edges where the support should be applied.

Apply force in the Z direction:

Right-click on "Static Structural" > Insert > Force.

Select the face or area where the force should be applied.

Specify the magnitude and direction of the force (Z direction).

f. Generate and Observe the Mesh

Click on "Mesh" in the Outline tree.

Click on "Generate Mesh" to create the mesh.

Observe the mesh view to ensure proper element distribution.

g. Insert and Review Results

Insert the required results:

Right-click on "Solution" in the Outline tree > Insert > Deformation > Total.

Right-click on "Solution" > Insert > Stress > Equivalent (von Mises).

Solve the analysis:

Click on "Solve" to run the simulation.

Review the results:

Check the total deformation, stress distributions, and any other inserted results.

This standard procedure for structural analysis in ANSYS covers the essential steps to set up and analyze a static structural problem using Mild Steel as the material. Ensure all inputs and settings are correct before simulating to obtain accurate results.

7. ANALYSIS OF RESULTS

7.1 CAD Design Model:

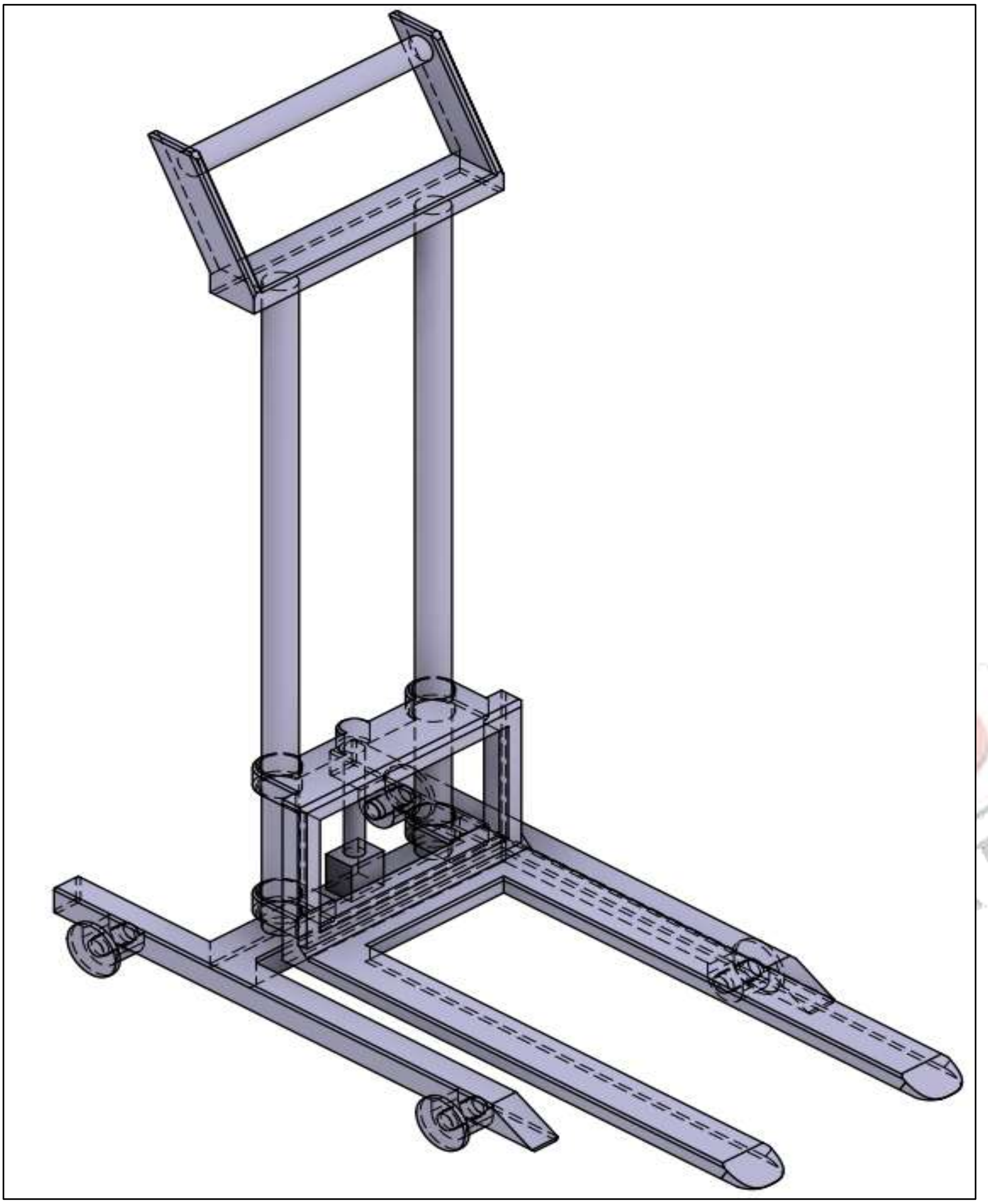

Figure 2: CAD Design Model of Manual Forklift

7.2 Analysis Model:

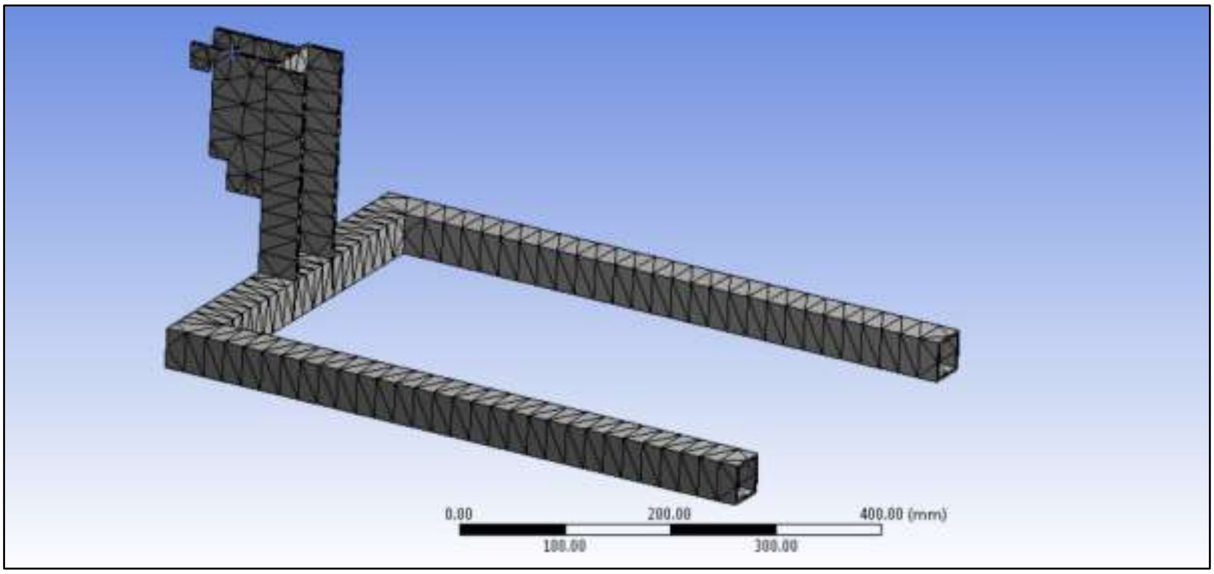

Figure 3: Meshing Model of Fork Using ANSYS

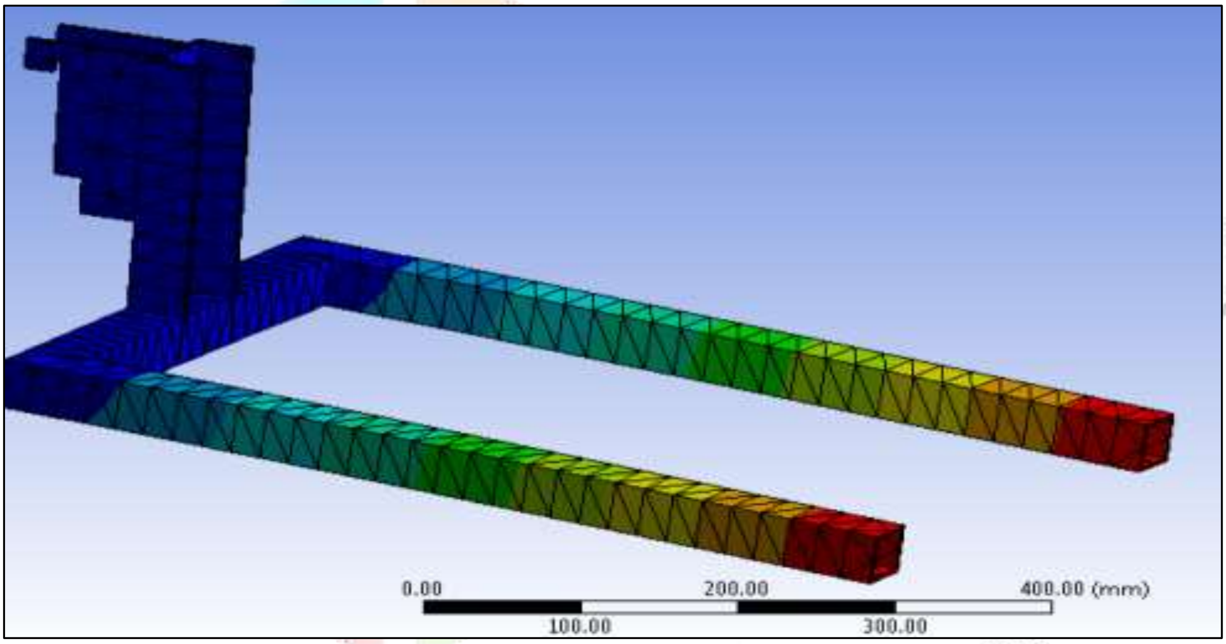

Figure 4: Analysis of Fork Using ANSYS

7.3 Results of Analysis:

a. We analyzed a design with various materials and their independent variables. The dimensions of the design are as follows: width of 101.68 mm, thickness of 38.1 mm, and length of 990.6 mm.

Table 1: Result for ITA = 254

Material	Directional Deformation Maximum (mm)	Normal Elastic Strain (mm/mm)	Shear Elastic Strain (mm/mm)	Normal Stress (MPa)	Shear Stress (MPa)
Structural Steel	1.03×10^{-2}	Max= 2.9×10^{-4} Min= -1.9×10^{-4} Avg.= 7.1×10^{-7}	Max= 1.8×10^{-4} Min= -1.8×10^{-4} Avg.= -1.55×10^{-7}	Max= 54.3 Min= -47.8 Avg.= 0.378	Max= 14.05 Min= -14.46 Avg.= -1.2×10^{-2}
Gray Cast Iron	1.81×10^{-2}	Max= 4.2×10^{-4} Min= -3.7×10^{-4} Avg.= 1.07×10^{-7}	Max= 2.7×10^{-4} Min= -2.5×10^{-4} Avg.= 2.9×10^{-7}	Max= 49.08 Min= -48.7 Avg.= 0.116	Max= 11.67 Min= -11.17 Avg.= 1.2×10^{-2}
Stainless Steel	1.1×10^{-2}	Max= 2.4×10^{-4} Min= -2.1×10^{-4} Avg.= 2.1×10^{-9}	Max= 1.6×10^{-4} Min= -1.5×10^{-4} Avg.= 1.7×10^{-7}	Max= 49.50 Min= -49.42 Avg.= 0.116	Max= 11.71 Min= -11.3 Avg.= 1.26×10^{-2}
Aluminium Alloy	3.15×10^{-2}	Max= 6.9×10^{-4} Min= -5.3×10^{-4} Avg.= 1.6×10^{-6}	Max= 5.2×10^{-4} Min= -5.4×10^{-4} Avg.= -4.4×10^{-7}	Max= 54.6 Min= -48.34 Avg.= 0.382	Max= 14.09 Min= -14.61 Avg.= -1.18×10^{-2}

Table 2: Result for ITA = 266.7

Material	Directional Deformation Maximum (mm)	Normal Elastic Strain (mm/mm)	Shear Elastic Strain (mm/mm)	Normal Stress (MPa)	Shear Stress (MPa)
Structural Steel	5.8×10^{-2}	Max= 2.6×10^{-4} Min= -2.7×10^{-4} Avg.= 5.5×10^{-7}	Max= 2×10^{-4} Min= -1.7×10^{-4} Avg.= -5.6×10^{-8}	Max= 54.9 Min= -65.2 Avg.= 0.353	Max= 15.76 Min= -13.24 Avg.= -4.3×10^{-3}
Gray Cast Iron	0.1068	Max= 4.7×10^{-4} Min= -5.03×10^{-4} Avg.= 1.1×10^{-6}	Max= 3.6×10^{-4} Min= -3.07×10^{-4} Avg.= -1.04×10^{-7}	Max= 54.7 Min= -64.5 Avg.= 0.350	Max= 15.70 Min= -13.20 Avg.= -4.51×10^{-3}
Stainless Steel	6.08×10^{-2}	Max= 2.7×10^{-4} Min= -2.8×10^{-4} Avg.= 5.3×10^{-7}	Max= 2.1×10^{-4} Min= -1.79×10^{-4} Avg.= -5.8×10^{-8}	Max= 55.03 Min= -65.56 Avg.= 0.354	Max= 15.79 Min= -13.20 Avg.= -4.31×10^{-3}
Aluminium Alloy	0.1068	Max= 7.3×10^{-4} Min= -7.4×10^{-4} Avg.= 1.24×10^{-6}	Max= 5.9×10^{-4} Min= -4.97×10^{-4} Avg.= -1.6×10^{-7}	Max= 55.2 Min= -66.32 Avg.= 0.357	Max= 15.85 Min= -13.20 Avg.= -4.18×10^{-3}

Table 3: Result for ITA = 279.4

Material	Directional Deformation Maximum (mm)	Normal Elastic Strain (mm/mm)	Shear Elastic Strain (mm/mm)	Normal Stress (MPa)	Shear Stress (MPa)
Structural Steel	1.03×10^{-2}	Max= 2.48×10^{-4} Min= -2.55×10^{-4} Avg.= 8.5×10^{-7}	Max= 2.55×10^{-4} Min= -1.8×10^{-4} Avg.= -2.1×10^{-7}	Max= 55.3 Min= -61.57 Avg.= 0.426	Max= 19.68 Min= -14.08 Avg.= -1.62×10^{-2}
Gray Cast Iron	1.78×10^{-2}	Max= 4.52×10^{-4} Min= -4.71×10^{-4} Avg.= 1.7×10^{-6}	Max= 4.56×10^{-4} Min= -3.28×10^{-4} Avg.= -3.7×10^{-7}	Max= 55.08 Min= -60.98 Avg.= 0.422	Max= 19.62 Min= -14.12 Avg.= -1.62×10^{-2}
Stainless Steel	1.1×10^{-2}	Max= 2.54×10^{-4} Min= -2.62×10^{-4} Avg.= 8.4×10^{-7}	Max= 2.67×10^{-4} Min= -1.91×10^{-4} Avg.= -2.1×10^{-7}	Max= 55.43 Min= -61.9 Avg.= 0.427	Max= 19.7 Min= -14.07 Avg.= -1.61×10^{-2}
Aluminium Alloy	3.15×10^{-2}	Max= 6.98×10^{-4} Min= -6.99×10^{-4} Avg.= 2.08×10^{-6}	Max= 7.4×10^{-4} Min= -5.25×10^{-4} Avg.= -6×10^{-7}	Max= 55.64 Min= -62.59 Avg.= 0.430	Max= 19.75 Min= -14.03 Avg.= -1.61×10^{-2}

Table 4: Result for ITA = 292.1

Material	Directional Deformation Maximum (mm)	Normal Elastic Strain (mm/mm)	Shear Elastic Strain (mm/mm)	Normal Stress (MPa)	Shear Stress (MPa)
Structural Steel	1.03×10^{-2}	Max= 2.34×10^{-4} Min= -2.91×10^{-4} Avg.= 4.74×10^{-7}	Max= 2.16×10^{-4} Min= -1.9×10^{-4} Avg.= -1.5×10^{-7}	Max= 55.42 Min= -69.81 Avg.= 0.344	Max= 16.62 Min= -14.64 Avg.= -1.16×10^{-2}
Gray Cast Iron	1.78×10^{-2}	Max= 4.26×10^{-4} Min= -5.36×10^{-4} Avg.= 9.9×10^{-7}	Max= 3.85×10^{-4} Min= -3.4×10^{-4} Avg.= -2.72×10^{-7}	Max= 55.10 Min= -69.19 Avg.= 0.341	Max= 16.57 Min= -14.62 Avg.= -1.17×10^{-2}
Stainless Steel	3.16×10^{-2}	Max= 6.57×10^{-4} Min= -7.93×10^{-4} Avg.= 1.01×10^{-6}	Max= 6.25×10^{-4} Min= -5.4×10^{-4} Avg.= -4.3×10^{-7}	Max= 55.87 Min= -70.86 Avg.= 0.349	Max= 16.69 Min= -14.67 Avg.= -1.14×10^{-2}
Aluminium Alloy	1.1×10^{-2}	Max= 2.42×10^{-4} Min= -2.97×10^{-4} Avg.= 4.52×10^{-7}	Max= 2.26×10^{-4} Min= -1.99×10^{-4} Avg.= -1.5×10^{-7}	Max= 55.58 Min= -70.15 Avg.= 0.346	Max= 16.65 Min= -14.66 Avg.= -1.15×10^{-2}

Table 5: Result for ITA = 304

Material	Directional Deformation Maximum (mm)	Normal Elastic Strain (mm/mm)	Shear Elastic Strain (mm/mm)	Normal Stress (MPa)	Shear Stress (MPa)
Structural Steel	1.03×10^{-2}	Max= 2.4×10^{-4} Min= -2.89×10^{-4} Avg.= 3.1×10^{-7}	Max= 1.77×10^{-4} Min= -1.72×10^{-4} Avg.= -1.4×10^{-7}	Max= 53.85 Min= -69.16 Avg.= 0.307	Max= 13.62 Min= -13.27 Avg.= -1.10×10^{-2}
Gray Cast Iron	1.1×10^{-2}	Max= 2.53×10^{-4} Min= -2.97×10^{-4} Avg.= 2.82×10^{-7}	Max= 1.84×10^{-4} Min= -1.8×10^{-4} Avg.= -1.4×10^{-7}	Max= 53.95 Min= -69.54 Avg.= 0.308	Max= 13.62 Min= -13.28 Avg.= -1.09×10^{-2}
Stainless Steel	1.78×10^{-2}	Max= 4.45×10^{-4} Min= -5.34×10^{-4} Avg.= 7×10^{-7}	Max= 3.16×10^{-4} Min= -3.08×10^{-4} Avg.= -2.5×10^{-7}	Max= 53.61 Min= -69.47 Avg.= 0.305	Max= 13.61 Min= -13.25 Avg.= -1.11×10^{-2}
Aluminium Alloy	3.15×10^{-2}	Max= 6.36×10^{-4} Min= -7.95×10^{-4} Avg.= 5.4×10^{-7}	Max= 5.1×10^{-4} Min= -4.98×10^{-4} Avg.= -4.05×10^{-7}	Max= 54.15 Min= -70.34 Avg.= 0.311	Max= 13.62 Min= -13.30 Avg.= -1.08×10^{-2}

Table 6: Result for ITA = 317.5

Material	Directional Deformation Maximum (mm)	Normal Elastic Strain (mm/mm)	Shear Elastic Strain (mm/mm)	Normal Stress (MPa)	Shear Stress (MPa)
Structural Steel	1.02×10^{-2}	Max= 2.47×10^{-4} Min= -2.69×10^{-4} Avg.= 4.5×10^{-7}	Max= 1.82×10^{-4} Min= -1.86×10^{-4} Avg.= -2.6×10^{-7}	Max= 53.42 Min= -65.21 Avg.= 0.337	Max= 14.17 Min= -14.30 Avg.= -2.01×10^{-2}
Gray Cast Iron	3.13×10^{-2}	Max= 6.96×10^{-4} Min= -7.37×10^{-4} Avg.= 9.4×10^{-7}	Max= 5.08×10^{-4} Min= -5.30×10^{-4} Avg.= -7.4×10^{-7}	Max= 53.71 Min= -66.33 Avg.= 0.342	Max= 13.57 Min= -14.37 Avg.= -2×10^{-2}
Stainless Steel	1.77×10^{-2}	Max= 4.51×10^{-4} Min= -4.97×10^{-4} Avg.= 9.5×10^{-7}	Max= 3.39×10^{-4} Min= -3.31×10^{-4} Avg.= -4.7×10^{-7}	Max= 53.22 Min= -64.55 Avg.= 0.335	Max= 14.57 Min= -14.25 Avg.= -2.03×10^{-2}
Aluminium Alloy	1.09×10^{-2}	Max= 2.56×10^{-4} Min= -2.76×10^{-4} Avg.= 4.2×10^{-7}	Max= 1.89×10^{-4} Min= -1.94×10^{-4} Avg.= -2.7×10^{-7}	Max= 53.50 Min= -65.57 Avg.= 0.339	Max= 13.97 Min= -14.33 Avg.= -2.01×10^{-2}

Table 7: Result for ITA = 330.2

Material	Directional Deformation Maximum (mm)	Normal Elastic Strain (mm/mm)	Shear Elastic Strain (mm/mm)	Normal Stress (MPa)	Shear Stress (MPa)
Structural Steel	1.03×10^{-2}	Max= 2.61×10^{-4} Min= -2.3×10^{-4} Avg.= 4.14×10^{-7}	Max= 2.03×10^{-4} Min= -1.88×10^{-4} Avg.= -9.7×10^{-8}	Max= 54.32 Min= -56.98 Avg.= 0.334	Max= 15.68 Min= -14.48 Avg.= -7.49×10^{-3}
Gray Cast Iron	1.78×10^{-2}	Max= 4.76×10^{-4} Min= -4.3×10^{-4} Avg.= 8.94×10^{-7}	Max= 3.63×10^{-4} Min= -3.35×10^{-4} Avg.= -1.7×10^{-7}	Max= 54.44 Min= -56.53 Avg.= 0.331	Max= 15.63 Min= -14.41 Avg.= -7.63×10^{-3}
Stainless Steel	3.16×10^{-2}	Max= 7.35×10^{-4} Min= -6.4×10^{-4} Avg.= 8.39×10^{-7}	Max= 5.9×10^{-4} Min= -5.46×10^{-4} Avg.= -2.7×10^{-7}	Max= 55.11 Min= -57.75 Avg.= 0.339	Max= 15.76 Min= -14.58 Avg.= -7.27×10^{-3}
Aluminium Alloy	1.10×10^{-2}	Max= 2.7×10^{-4} Min= -2.4×10^{-4} Avg.= 3.89×10^{-7}	Max= 2.1×10^{-4} Min= -1.9×10^{-4} Avg.= -1×10^{-7}	Max= 54.86 Min= -57.23 Avg.= 0.336	Max= 15.71 Min= -14.51 Avg.= -7.42×10^{-3}

b. We analyzed a design with various materials and their independent variables. The dimensions of the design are as follows: width of 101.68 mm, thickness of 38.1 mm, and length of 1016 mm.

Table 8: Result for ITA = 254

Material	Directional Deformation Maximum (mm)	Normal Elastic Strain (mm/mm)	Shear Elastic Strain (mm/mm)	Normal Stress (MPa)	Shear Stress (MPa)
Structural Steel	1.11×10^{-2}	Max= 2.59×10^{-4} Min= -2.84×10^{-4} Avg.= 1.46×10^{-6}	Max= 1.76×10^{-4} Min= -2.67×10^{-4} Avg.= -3.7×10^{-7}	Max= 57.62 Min= -69.29 Avg.= 0.538	Max= 13.60 Min= -20.51 Avg.= -2.91×10^{-2}
Gray Cast Iron	3.38×10^{-2}	Max= 7.29×10^{-4} Min= -7.75×10^{-4} Avg.= 3.80×10^{-6}	Max= 5.13×10^{-4} Min= -7.69×10^{-4} Avg.= -1.08×10^{-6}	Max= 58.13 Min= -70.35 Avg.= 0.542	Max= 13.71 Min= -20.54 Avg.= -2.90×10^{-2}
Stainless Steel	1.91×10^{-2}	Max= 4.71×10^{-4} Min= -5.26×10^{-4} Avg.= 2.79×10^{-6}	Max= 3.15×10^{-4} Min= -4.76×10^{-4} Avg.= -6.7×10^{-7}	Max= 57.27 Min= -68.65 Avg.= 0.535	Max= 13.54 Min= -20.49 Avg.= -2.91×10^{-2}
Aluminium Alloy	1.18×10^{-2}	Max= 2.68×10^{-4} Min= -2.91×10^{-4} Avg.= 1.47×10^{-6}	Max= 1.85×10^{-4} Min= -2.78×10^{-4} Avg.= -3.94×10^{-7}	Max= 57.79 Min= -69.63 Avg.= 0.539	Max= 13.64 Min= -20.52 Avg.= -2.90×10^{-2}

Table 9: Result for ITA = 266.7

Material	Directional Deformation Maximum (mm)	Normal Elastic Strain (mm/mm)	Shear Elastic Strain (mm/mm)	Normal Stress (MPa)	Shear Stress (MPa)
Structural Steel	1.09×10^{-2}	Max= 2.57×10^{-4} Min= -2.8×10^{-4} Avg.= 1.65×10^{-6}	Max= 2.08×10^{-4} Min= -2.05×10^{-4} Avg.= -1.71×10^{-7}	Max= 57.25 Min= -68.14 Avg.= 0.58	Max= 16.01 Min= -15.82 Avg.= -1.31×10^{-2}
Gray Cast Iron	3.34×10^{-2}	Max= 7.23×10^{-4} Min= -7.67×10^{-4} Avg.= 4.33×10^{-6}	Max= 6.01×10^{-4} Min= -5.93×10^{-4} Avg.= -4.8×10^{-7}	Max= 57.70 Min= -69.18 Avg.= 0.59	Max= 16.04 Min= -15.84 Avg.= -1.24×10^{-2}
Stainless Steel	1.89×10^{-2}	Max= 4.67×10^{-4} Min= -5.19×10^{-4} Avg.= 3.15×10^{-6}	Max= 3.71×10^{-4} Min= -3.67×10^{-4} Avg.= -3.11×10^{-7}	Max= 56.94 Min= -67.52 Avg.= 0.58	Max= 15.98 Min= -15.79 Avg.= -1.33×10^{-2}
Aluminium Alloy	1.16×10^{-2}	Max= 2.66×10^{-4} Min= -2.88×10^{-4} Avg.= 1.67×10^{-6}	Max= 2.17×10^{-4} Min= -2.14×10^{-4} Avg.= -1.7×10^{-7}	Max= 57.40 Min= -68.47 Avg.= 0.58	Max= 16.02 Min= -15.83 Avg.= -1.3×10^{-2}

Table 10: Result for ITA = 279.4

Material	Directional Deformation Maximum (mm)	Normal Elastic Strain (mm/mm)	Shear Elastic Strain (mm/mm)	Normal Stress (MPa)	Shear Stress (MPa)
Structural Steel	1.09×10^{-2}	Max= 2.43×10^{-4} Min= -2.42×10^{-4} Avg.= 1.34×10^{-6}	Max= 1.62×10^{-4} Min= -2.74×10^{-4} Avg.= -4.9×10^{-7}	Max= 56.75 Min= -57.83 Avg.= 0.51	Max= 12.51 Min= -21.13 Avg.= -3.7×10^{-2}
Gray Cast Iron	3.36×10^{-2}	Max= 6.82×10^{-4} Min= -6.65×10^{-4} Avg.= 3.46×10^{-6}	Max= 4.67×10^{-4} Min= -7.94×10^{-4} Avg.= -1.41×10^{-6}	Max= 57.19 Min= -58.82 Avg.= 0.51	Max= 12.47 Min= -21.21 Avg.= -3.78×10^{-2}
Stainless Steel	1.89×10^{-2}	Max= 4.43×10^{-4} Min= -4.47×10^{-4} Avg.= 2.58×10^{-6}	Max= 2.91×10^{-4} Min= -4.90×10^{-4} Avg.= -8.77×10^{-7}	Max= 56.45 Min= -57.25 Avg.= 0.51	Max= 12.53 Min= -21.08 Avg.= -3.76×10^{-2}
Aluminium Alloy	1.67×10^{-2}	Max= 2.51×10^{-4} Min= -2.49×10^{-4} Avg.= 1.35×10^{-6}	Max= 1.69×10^{-4} Min= -2.87×10^{-4} Avg.= -5.1×10^{-7}	Max= 56.91 Min= -58.14 Avg.= 0.51	Max= 12.50 Min= -21.16 Avg.= -3.78×10^{-2}

Table 11: Result for ITA = 292.1

Material	Directional Deformation Maximum (mm)	Normal Elastic Strain (mm/mm)	Shear Elastic Strain (mm/mm)	Normal Stress (MPa)	Shear Stress (MPa)
Structural Steel	1.09×10^{-2}	Max= 2.56×10^{-4} Min= -2.16×10^{-4} Avg.= 1.32×10^{-6}	Max= 1.76×10^{-4} Min= -1.9×10^{-4} Avg.= -2.3×10^{-7}	Max= 54.27 Min= -52.56 Avg.= 0.50	Max= 13.58 Min= -14.67 Avg.= -1.84×10^{-2}
Gray Cast Iron	3.33×10^{-2}	Max= 7.21×10^{-4} Min= -5.4×10^{-4} Avg.= 3.42×10^{-6}	Max= 5.1×10^{-4} Min= -5.54×10^{-4} Avg.= -6.9×10^{-7}	Max= 54.58 Min= -53.24 Avg.= 0.50	Max= 13.61 Min= -14.79 Avg.= -1.84×10^{-2}
Stainless Steel	1.89×10^{-2}	Max= 4.67×10^{-4} Min= -3.9×10^{-4} Avg.= 2.5×10^{-6}	Max= 3.15×10^{-4} Min= -3.39×10^{-4} Avg.= -4.2×10^{-7}	Max= 54.02 Min= -52.14 Avg.= 0.50	Max= 13.56 Min= -14.58 Avg.= -1.84×10^{-2}
Aluminium Alloy	1.16×10^{-2}	Max= 2.65×10^{-4} Min= -2.21×10^{-4} Avg.= 1.33×10^{-6}	Max= 1.85×10^{-4} Min= -2×10^{-4} Avg.= -2.5×10^{-7}	Max= 54.38 Min= -52.71 Avg.= 0.50	Max= 13.59 Min= -14.70 Avg.= -1.84×10^{-2}

Table 12: Result for ITA = 304

Material	Directional Deformation Maximum (mm)	Normal Elastic Strain (mm/mm)	Shear Elastic Strain (mm/mm)	Normal Stress (MPa)	Shear Stress (MPa)
Structural Steel	1.09×10^{-2}	Max= 2.4×10^{-4} Min= -3.4×10^{-4} Avg.= 1.5×10^{-6}	Max= 2.51×10^{-4} Min= -1.88×10^{-4} Avg.= 2.75×10^{-8}	Max= 56.11 Min= -82.31 Avg.= 0.55	Max= 19.33 Min= -14.46 Avg.= 2.11×10^{-3}
Gray Cast Iron	3.33×10^{-2}	Max= 6.78×10^{-4} Min= -9.32×10^{-4} Avg.= 3.9×10^{-6}	Max= 7.29×10^{-4} Min= -5.42×10^{-4} Avg.= 7.83×10^{-8}	Max= 56.49 Min= -83.56 Avg.= 0.55	Max= 19.47 Min= -14.48 Avg.= 2.09×10^{-3}
Stainless Steel	1.88×10^{-2}	Max= 4.37×10^{-4} Min= -6.32×10^{-4} Avg.= 2.86×10^{-6}	Max= 4.47×10^{-4} Min= -3.35×10^{-4} Avg.= 4.9×10^{-8}	Max= 55.84 Min= -81.58 Avg.= 0.54	Max= 19.24 Min= -14.43 Avg.= 2.14×10^{-3}
Aluminium Alloy	1.16×10^{-2}	Max= 2.49×10^{-4} Min= -3.5×10^{-4} Avg.= 1.51×10^{-6}	Max= 2.63×10^{-4} Min= -1.96×10^{-4} Avg.= 2.8×10^{-8}	Max= 56.24 Min= -82.71 Avg.= 0.55	Max= 19.38 Min= -14.47 Avg.= 2.10×10^{-3}

Table 13: Result for ITA = 317.5

Material	Directional Deformation Maximum (mm)	Normal Elastic Strain (mm/mm)	Shear Elastic Strain (mm/mm)	Normal Stress (MPa)	Shear Stress (MPa)
Structural Steel	1.09×10^{-2}	Max= 2.56×10^{-4} Min= -3.46×10^{-4} Avg.= 1.64×10^{-6}	Max= 2.11×10^{-4} Min= -1.96×10^{-4} Avg.= -5.76×10^{-8}	Max= 56.62 Min= -83.51 Avg.= 0.58	Max= 16.29 Min= -15.15 Avg.= -4.43×10^{-3}
Gray Cast Iron	3.34×10^{-2}	Max= 7.21×10^{-4} Min= -9.46×10^{-4} Avg.= 4.3×10^{-6}	Max= 6.13×10^{-4} Min= -5.69×10^{-4} Avg.= -1.7×10^{-7}	Max= 56.87 Min= -84.78 Avg.= 0.58	Max= 16.36 Min= -15.19 Avg.= -4.59×10^{-3}
Stainless Steel	1.89×10^{-2}	Max= 4.67×10^{-4} Min= -6.41×10^{-4} Avg.= 3.13×10^{-6}	Max= 3.78×10^{-4} Min= -3.51×10^{-4} Avg.= -1×10^{-7}	Max= 56.40 Min= -82.76 Avg.= 0.58	Max= 16.24 Min= -15.11 Avg.= -4.33×10^{-3}
Aluminium Alloy	1.16×10^{-2}	Max= 2.65×10^{-4} Min= -3.55×10^{-4} Avg.= 1.67×10^{-6}	Max= 2.21×10^{-4} Min= -2.05×10^{-4} Avg.= -6.09×10^{-8}	Max= 56.71 Min= -83.91 Avg.= 0.58	Max= 16.32 Min= -15.16 Avg.= -4.48×10^{-3}

Table 14: Result for ITA = 330.2

Material	Directional Deformation Maximum (mm)	Normal Elastic Strain (mm/mm)	Shear Elastic Strain (mm/mm)	Normal Stress (MPa)	Shear Stress (MPa)
Structural Steel	1.1×10^{-2}	Max= 2.44×10^{-4} Min= -2.34×10^{-4} Avg.= 1.18×10^{-6}	Max= 1.87×10^{-4} Min= -2.24×10^{-4} Avg.= -3.7×10^{-7}	Max= 57.82 Min= -57.34 Avg.= 0.48	Max= 14.41 Min= -18.01 Avg.= -2.85×10^{-2}
Gray Cast Iron	3.35×10^{-2}	Max= 6.88×10^{-4} Min= -6.36×10^{-4} Avg.= 3.01×10^{-6}	Max= 5.41×10^{-4} Min= -6.76×10^{-4} Avg.= -1.06×10^{-6}	Max= 58.25 Min= -57.88 Avg.= 0.48	Max= 14.45 Min= -18.06 Avg.= -2.84×10^{-2}
Stainless Steel	1.89×10^{-2}	Max= 4.45×10^{-4} Min= -4.35×10^{-4} Avg.= 2.28×10^{-6}	Max= 3.34×10^{-4} Min= -4.18×10^{-4} Avg.= -6.64×10^{-7}	Max= 57.53 Min= -57.02 Avg.= 0.47	Max= 14.37 Min= -17.97 Avg.= -2.85×10^{-2}
Aluminium Alloy	1.17×10^{-2}	Max= 2.53×10^{-4} Min= -2.4×10^{-4} Avg.= 1.18×10^{-6}	Max= 1.95×10^{-4} Min= -2.44×10^{-4} Avg.= -3.8×10^{-7}	Max= 57.97 Min= -57.51 Avg.= 0.48	Max= 14.42 Min= -18.03 Avg.= -2.84×10^{-2}

8. CONCLUSION

The use of various materials for forklift forks results in minimal deformation, with mild steel demonstrating superior wear resistance and impact strength. The theoretical calculations, verified against ANSYS results, confirm the safety and reliability of these findings. The development of mechanical forklifts enhances ergonomic comfort for operators, significantly reducing the time needed for manual lifting and handling. These forklifts are capable of lifting loads to 500 kg at an ITA (Industrial Truck Association) rating of 990.6 mm and 1016 mm, thereby boosting productivity and ensuring operator safety during material handling tasks. The integration of these advanced features standardizes the forklift design, making it a robust and efficient tool in industrial applications.

9. FUTURE SCOPE

The future scope of manual forklifts includes significant advancements in ergonomic design, lightweight materials, and enhanced safety features. Innovations such as hybrid models that combine manual and motorized functions could emerge, offering greater versatility and ease of use. Additionally, integrating smart technology like IoT sensors and automated tracking systems can optimize inventory management and maintenance schedules. As sustainability becomes a priority, the development of eco-friendly materials and energy-efficient designs will likely gain traction. Overall, these advancements will make manual forklifts more efficient, user-friendly, and aligned with modern industrial and environmental standards.

REFERENCES:

1. Khebude Karan N, (B.E, Dept. of Mechanical Engineering, Sanjeevan Engineering & Technology Institute, Panhala, MH, India'' Design and Analysis of Mechanical Forklift'' International Journal of Scientific Research and Engineering Development- Volume 3 Issue 2, Mar-Apr 2020.

2. Krunal R. Dhivar Lecturer Department of Mechanical Engineering L.I.T. Sarigam, Valsad, India "Construction of Battery-Operated Forklift" (IJSTE - International Journal of Science Technology & Engineering | Volume 2 | Issue 4 | October 2015 ISSN (online): 2349-784X).

3. Dr. V. R. Gandhewar1, Kalyani R. Bhokare2, Chirag D. Pande3, Vaibhav G. Mali4, Ganesh V. Badaki5 Assistant Professor1, BE Student 2, 3, 4, 5 Department of Mechanical Jawaharlal Darda Institute of Engineering and Technology, Yavatmal, Maharashtra, India "Battery Operated Forklift Vehicle.'' (2018 IJESC Volume 8 Issue No.4).

4. Prof. Suryavanshi Amol V Faculty of Department of Mechanical Engineering, PCCOE Savitribai Phule Pune University. "Design of Electric Forklift used in Small industrial Warehouses and Workshops" International Journal of Engineering Research & Technology (IJERT).

5. Jayesh Yadav, Manish Vishwakarma, Siddiqui Mohd Shakir, Sanoj Yadav, Yusuf Rehman, Department of Mechanical Engineering, Theem College of Engineering. "Design and Fabrication of Electric Forklift". (IJRASET, vol. 10, issue IV, 2022).

6. Amboji Sudhakar, Humane Yogesh, Chavan Rohan, Patil Jyotsna, Kshirsagar Prashant, "Design and Fabrication of Three-Way Tipper Mechanism", International Journal of Research in Advent Technology, 2(4), 261-265, 2014.

7. Kaushik Panara, Vivek Mishra, Amrat Patel, Tushar Patel, Krunal Dhivar, "Construction of Battery-Operated Forklift", International Journal of Science Technology and Engineering, 2(4), 2015.