Design and Fabrication of Solar Electric Vehicle

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DEDICATION

Dedicated to my exceptional parents and Teachers, whose tremendous support and cooperation led me to this wonderful accomplishment.

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ABSTRACT

This thesis presents a comprehensive exploration into the design, fabrication, and real-world implementation of a solar electric vehicle (SEV) featuring a ladder frame chassis. Motivated by the increasing demand for environmentally sustainable transportation solutions, this study aims to revolutionize vehicle architecture by prioritizing economy, scalability, and adaptability. Beginning with meticulous design selections and CAD modeling, the ladder frame chassis was crafted to optimize structural integrity while minimizing weight. Inspired by nature's efficiency, the design strategy sought to strike a balance between weight reduction and robustness, facilitated by SolidWorks software. Subsequent finite element analysis (FEA) simulations using ANSYS software validated the chassis's structural performance and safety under static structural loads and torsional forces. Crucial parameters such as total deformation and stress distributions were scrutinized, affirming the chassis's resilience under diverse loading conditions. The culmination of this research involved the fabrication of the SEV and its successful road testing, underscoring the practical viability of the design. By translating theoretical concepts into tangible results, this thesis demonstrates the efficacy of the ladder frame chassis in real-world driving scenarios, affirming its potential to enhance both performance and safety. The study concludes with forward-looking perspectives, suggesting avenues for further refinement and optimization. Continued research into advanced materials, component arrangements, and performance evaluations promises to further enhance the SEV's efficiency and applicability in sustainable transportation systems.

Keywords: Ladder Frame Chassis, Solar Electric Vehicle, Sustainability.

CHAPTER 1 : INTRODUCTION

1.1 Background

Recently, there has been an increasing global concern over the reliance on fossil fuels and its negative effects on the environment (Johnsson et al., 2019, Abbasi et al., 2022, Holechek et al., 2022). The usage of conventional internal combustion engine cars not only has a substantial impact on the release of greenhouse gases but also exhausts limited fossil fuel reserves. The transportation industry significantly contributes to global greenhouse gas emissions and reliance on fossil fuels (Santos et al., 2021, Gheidan et al., 2022, Bieker, 2021, Leach et al., 2020). The transport industry was responsible for around 25% of worldwide energy-related carbon dioxide (CO_2) emissions in 2020, with road vehicles being the primary source (Zhou et al., 2019). The reliance on fossil fuels presents a substantial risk to the long-term viability of the ecosystem and exacerbates the issue of climate change (Hansen et al., 2013, Malhi et al., 2020, Turton and Barreto, 2006). In addition, the burning of fossil fuels emits pollutants that deteriorate air quality and negatively impact human health. As a reaction to these difficulties, the creation and acceptance of Sustainable Energy Vehicles (SEVs) has become a vital answer (Gaffney and Marley, 2009, Wang and Hao, 2012, Mobarak et al., 2020, Nawaz et al., 2024).

SEVs, namely electric vehicles (EVs), provide a hopeful substitute for traditional gasoline-powered automobiles. SEVs effectively minimize or eliminate tailpipe emissions by employing electric power, so mitigating air pollution and minimizing the carbon footprint associated with mobility. Moreover, the use of renewable energy sources to power SEVs significantly improves their ecological sustainability. SEVs provide a multitude of possible advantages (Zhang et al., 2018, Hossain et al., 2022, Falahi et al., 2013, Tseng et al., 2013):

- SEVs provide a substantial contribution to reducing greenhouse gas emissions and addressing climate change by eliminating the usage of fossil fuels.
- Diminished dependency on fossil fuels: SEVs mitigate dependence on limited oil supplies and enhance energy security.
- Enhanced air quality: Electric motors generate zero tailpipe emissions, resulting in a more pristine atmosphere in metropolitan areas.

- Reduced operational expenses: SEVs have decreased fuel and maintenance costs in comparison to gasoline cars.

The chassis is of utmost importance in ensuring the structural integrity and performance of a SEV. The chassis serves as the foundation on which all other elements, including the drivetrain, suspension, and body panels, are attached (Tseng et al., 2013). The chassis of electric cars must not only provide structural support but also fit the specific needs of these vehicles, such as the positioning of batteries and the distribution of weight. Traditional chassis type include:

3.2.1 Ladder Frame Chassis

A ladder frame chassis is composed of two parallel longitudinal rails, often referred to as "rails," that are connected by lateral cross members. This design has a combination of simplicity, robustness, and long-lastingness, making it highly suitable for demanding uses like trucks and off-road vehicles. Nevertheless, ladder frame chassis are often characterized by their increased weight and reduced rigidity in comparison to other designs, resulting in potential consequences for handling and fuel economy (Christensen and Bastien, 2016).

3.2.2 Monocoque Chassis:

A monocoque chassis is a kind of vehicle frame where the body and structure are integrated into a single unit, providing strength and rigidity. Monocoque chassis, or unibody architecture, combines the body and chassis of a vehicle into a single structure. This design provides enhanced stiffness and handling properties, which contribute to higher performance and safety. Monocoque chassis are often used in passenger automobiles and high-performance vehicles because of their lightweight design and adaptability (Gudmundsson, 2014).

When evaluating chassis options for SEVs, certain criteria are considered:

i. **Strength and Durability:** Ladder frame chassis are well-known for their sturdy design, providing great resilience and longevity. Their strong structural integrity makes them ideal for bearing the extra weight of battery packs and electric powertrain components in SEVs (Gurjar et al., 2019).

ii. **Customization and Versatility:** SEV manufacturers may easily modify ladder frame chassis to fit multiple battery configurations or vehicle layouts without affecting structural integrity because to its modular nature (Dagdeviren et al., 2016, Muthyala, 2019a).

iii. **Cost Effectiveness:** Ladder frame chassis are often more economical to produce in comparison to intricate monocoque designs. The affordability of SEVs may result in reduced manufacturing expenses, hence increasing their accessibility to a broader spectrum of customers (Mgbemena et al., 2019, Singh et al., 2014).

iv. **Repairability and Maintenance:** When there is damage or a collision, ladder frame chassis are often more convenient and cost-effective to fix in comparison to monocoque constructions. SEV owners may minimize downtime and maintenance costs by replacing or repairing individual components without the need for substantial disassembly of the vehicle. Furthermore, the modular structure of the ladder frame chassis allows for easy access to vehicle components, making regular maintenance jobs like battery replacement or drivetrain inspection simpler.

1.3 Problem Statement

The automobile industry worldwide is now experiencing a significant change towards sustainable transportation solutions to tackle issues related to reliance on fossil fuels, environmental consequences, and the long-term availability of energy. As a result of this fundamental change in thinking, the creation of Solar Electric Vehicles (SEVs) has become a potential approach to decrease greenhouse gas emissions, encourage the use of renewable energy, and improve energy efficiency in urban transportation.

Although there is increasing interest and investment in SEV technology, there is still a notable lack of research and development focused on creating practical, easily accessible, and economically feasible SEV solutions. The current SEV prototypes often encounter difficulties associated with intricate design, expandability in manufacturing, optimization of performance, and cost-efficiency, which restrict their extensive acceptance and market reach.

This thesis intends to tackle these problems by concentrating on the design and construction of a Solar Electric Vehicle (SEV), with a particular emphasis on the creation of a ladder frame chassis. The ladder frame chassis of the SEV functions as the structural base, providing support for crucial components like the electric powertrain, battery pack, and solar panels. It also ensures ideal weight distribution, longevity, and safety.

1.3 Aims & Objectives

The objective of this thesis is to create, manufacture, and verify a prototype of a Solar Electric Vehicle (SEV), with a specific emphasis on designing a ladder frame chassis to serve as the vehicle's main structural support. The main goal is to showcase the practicality and effectiveness of combining solar power technology with electric propulsion systems to provide a sustainable and eco-friendly method of urban transportation.

Specifically, the objectives include:

- Conduct a comprehensive literature survey on types of chassis frames, their stiffness characteristics, and suitable materials for solar electric vehicles.
- Utilize computer-aided drafting (CAD) software to generate multiple design iterations of the ladder frame chassis.
- Employ finite element analysis (FEA) to evaluate and refine the chassis designs and choose the design iteratively to satisfy key acceptance criteria like weight, strength, and stiffness.
- Select the final chassis design based on a combination of weight optimization through FEA.
- Fabricate the chosen chassis and assemble the complete solar electric vehicle using cost-effective and modular components.

1.1 Research Questions

- What are the primary criteria to consider when choosing a chassis type, such as ladder frame or space frame, for a solar electric vehicle, considering aspects like weight, rigidity, and ease of manufacturing?
- What are the common materials used in ladder frame construction for solar electric vehicles, and how do their properties (strength, weight, cost) influence the design process?
- How can finite element analysis (FEA) be used efficiently to improve the design of a ladder frame chassis for a solar electric vehicle, achieving a balance between reducing weight and maintaining structural integrity?

- What are the anticipated performance measures, such as range, efficiency, and handling, for the solar electric vehicle after it is equipped with the ladder frame chassis that has been designed?

CHAPTER 2 : LITERATURE REVIEW

Electric vehicles (EVs) have witnessed significant advancements over the past few decades, spurred by concerns over environmental sustainability and the need to reduce dependence on fossil fuels (Soares et al., 2018, Cao et al., 2021, Delucchi et al., 2014, Sperling, 2013). The history of EVs dates to the 19th century, with notable milestones including the invention of the electric car by William Morrison in the 1830s and the introduction of mass-produced electric vehicles in the early 20th century (Fattal, 2019). However, widespread adoption of EVs has been hindered by factors such as limited battery range, high costs, and inadequate charging infrastructure (Adhikari et al., 2020, Li et al., 2017).

In recent years, advancements in battery technology, electric drivetrains, and charging infrastructure have accelerated the adoption of EVs worldwide. The global EV market has experienced rapid growth, driven by government incentives, regulatory mandates, and increasing consumer awareness of environmental issues. Electric vehicles are now seen as a key solution to reducing greenhouse gas emissions and mitigating the impacts of climate change (Delucchi et al., 2014, Ellingsen et al., 2016, Zhang and Fujimori, 2020, Hill et al., 2019, Nanaki and Koroneos, 2016).

Solar vehicle technology has emerged as a promising solution for sustainable transportation, harnessing the power of the sun to generate clean, renewable energy. Over the years, significant progress has been made in the development of solar-powered vehicles, ranging from solar cars and bicycles to larger vehicles such as buses and trucks. Advances in solar panel efficiency, lightweight materials, and aerodynamic design have improved the performance and practicality of solar vehicles. Notable examples include the Solar Impulse aircraft, which completed a historic flight around the world powered solely by solar energy, and the World Solar Challenge, an annual solar car race that showcases the latest innovations in solar vehicle technology.

Previous research on solar electric vehicles (SEVs) has focused on various aspects of design, fabrication, and performance evaluation. Studies have explored different approaches to integrating solar panels into vehicle design, optimizing energy efficiency, and enhancing overall performance. Research projects such as the Stella Lux solar car and the Lightyear One solar electric vehicle have demonstrated the feasibility of SEVs for everyday transportation, achieving impressive range and efficiency using solar power alone. Challenges such as limited energy storage capacity and variable weather conditions continue to be areas of active research and innovation in the field of SEVs (López et al., 2019, Sarkar et al., 2014, Waseem et al., 2019, Mobarak et al., 2020).

The key components of solar electric vehicles include chassis, solar panels, battery systems, electric motors, and power management systems.

2.1 Chassis types

The chassis serves as the backbone of a SEV, providing structural integrity, supporting vehicle components, and ensuring safety. Principles of chassis design prioritize factors such as structural strength, weight distribution, and aerodynamics to optimize performance and efficiency (Mobarak et al., 2020). Various chassis architectures, including monocoque, ladder, and space frame designs, are employed in SEVs, each offering unique advantages in terms of weight savings, rigidity, and manufacturability (Reimpell et al., 2001). A ladder frame chassis is a classic and time-honored design that consists of two parallel longitudinal rails joined by lateral cross members. This design offers outstanding resilience and the ability to support enormous loads, making it ideal for demanding uses like trucks and off-road vehicles. Ladder frame chassis provides a straightforward and uncomplicated approach to building and fixing vehicles, enabling convenient access to vehicle parts and simple alterations. Nevertheless, these chassis design typically exhibit greater weight and reduced rigidity, resulting in potential repercussions for vehicle maneuverability and fuel economy .

A ladder frame chassis consists of two longitudinal rails, usually constructed from high-strength steel or other resilient materials, that extend from the front to the rear of the vehicle, forming its main framework. The rails serve as the primary structural support for the vehicle's body, engine, drivetrain, suspension, and other components. Typically, they are straight and have a box-shaped cross-section to provide sufficient strength and rigidity. The lateral cross members, which are commonly welded or bolted at a right angle to the longitudinal rails, serve to link and reinforce the two rails. The purpose of these cross members is to evenly distribute loads and strengthen the chassis against torsional pressures. Ladder frame chassis are renowned for their uncomplicated design and durability. The design exhibits exceptional endurance and load-bearing capacity, rendering it highly suitable for demanding applications such as trucks, SUVs, and off-road vehicles. The open frame design enables convenient access to vehicle components, hence enabling maintenance, repair, and alterations. This level of accessibility is especially beneficial in commercial and industrial settings where continuous operation and dependability are of utmost importance (Reimpell et al., 2001, Vignesh et al., 2022, Kunwar et al., 2023).

The production of ladder frame chassis is quite simple, involving basic welding and assembling methods. This straightforwardness enhances cost-efficiency and expandability in the manufacturing process. Ladder frame chassis offer remarkable strength and longevity, rendering them well-suited for challenging terrains and substantial loads. The ladder frame chassis's modular design enables convenient customization and adjustment to accommodate various vehicle kinds and uses. The open frame design enables easy access to vehicle components, streamlining maintenance and repair procedures. Ladder frame chassis are frequently more cost-effective to produce in comparison to intricate monocoque designs, resulting in reduced production expenses for cars (Christensen and Bastien, 2016, Patel and Patel, 2012).

2.2 Moment of inertia and Stiffness

Torsional stiffness, bending stiffness, and moment of inertia are crucial mechanical parameters in vehicle chassis design that greatly influence the performance and behavior of the vehicle (Danielsson et al., 2016, Barari et al., 2011).

Torsional rigidity refers to the ability of the chassis to withstand twisting or deformation caused by applied torque, such as while turning corners or driving on uneven terrain. A chassis possessing significant torsional stiffness preserves its structural integrity and stability, guaranteeing that the wheels sustain ideal contact with the road surface. Consequently, there is an enhancement in the vehicle's handling, responsiveness, and ride comfort due to the maintenance of a sturdy and stable chassis, which decreases the amount of body roll and enables more accurate steering control (Velie, 2016, Sampò, 2011, Belloni et al., 2024).

Bending stiffness, also known as flexural rigidity, is the capacity of the chassis to withstand bending or flexing when subjected to external forces. The feature in question is of utmost importance in preserving the shape and structural strength of the chassis, particularly when it is exposed to forces like crashes or uneven road surfaces. A chassis possessing a high degree of bending stiffness ensures that loads are uniformly distributed across its structure, hence limiting deformation and offering robust support for both vehicle components and people. This results in greater ride comfort, decreased vibration, and improved ability to withstand crashes, since the chassis maintains its rigidity and resilience throughout different driving situations (Kobelev, 2019, Sampò, 2011).

Moment of inertia pertains to the arrangement of mass in relation to an axis of rotation. The moment of inertia in chassis design directly affects the rotational reaction and agility of the chassis. A reduced moment of inertia indicates that the chassis has a smaller amount of mass spread farther from its rotating axis, leading to a faster rotational reaction and enhanced agility. This enables the vehicle to alter its direction more rapidly, enhancing the capacity to make sharper turns and improving stability, especially during high-speed maneuvers.

Attaining the ideal equilibrium of torsional rigidity, bending stiffness, and moment of inertia is essential in chassis design to guarantee the integrity of the structure, precision in handling, and overall performance of the vehicle. Engineers utilize sophisticated materials, implement geometric optimization techniques, and incorporate structural reinforcements to customize chassis designs for specific vehicle applications, ultimately improving safety, comfort, and driving experience. Through meticulous evaluation of these mechanical characteristics, chassis engineers can build automobiles that offer exceptional performance, stability, and ride comfort in many driving scenarios.

2.3 Materials

Material selection for chassis construction plays a pivotal role in achieving desired performance characteristics while minimizing weight and cost. (Desai et al., 2019) Common materials utilized in SEV chassis include aluminum alloys, high-strength steels, and advanced composites, each offering a balance of strength, stiffness, and weight savings. Steel is the preferred material for constructing car chassis due to its combination of essential characteristics that make it extremely suitable for this important part. The material's inherent robustness, longevity, and stiffness enable it to endure the various pressures and weights encountered by a vehicle while in use (Galos and Sutcliffe, 2020, ALVALI et al., 2021). The robustness of the chassis guarantees that it will keep its structural integrity over the lifecycle of the vehicle, offering crucial protection for both occupants and vehicle components. In addition, steel provides a superb ratio of strength to weight, enabling the creation of chassis designs that are both lightweight and structurally efficient. This, in turn, enhances fuel efficiency, driving dynamics, and overall performance. Moreover, steel's cost-efficiency in comparison to alternative materials such as aluminum or carbon fiber composites renders it a financially feasible option for chassis construction. In Pakistan, the abundant availability of steel facilitates local production and industrial expansion, hence decreasing reliance on imports and fostering economic sustainability (Babu et al., 2020, Desai et al., 2019). Utilizing domestically sourced steel resources improves the practicality and cost-effectiveness of automobile manufacturing in the country, providing a favorable and beneficial choice for vehicle producers. Therefore, the combination of steel's inherent characteristics and its easy accessibility in Pakistan strengthens its position as the favored material for chassis construction, enabling the manufacturing of long-lasting, efficient, and economically viable vehicles designed to meet the specific demands of the local market (Ramteke et al., 2022, ALVALI et al., 2021, Desai et al., 2019).

2.4 Connectivity

Techniques for chassis fabrication encompass a range of processes, including welding, forming, CNC machining, and additive manufacturing, enabling the realization of complex geometries and optimized structures (Li et al., 2024).

When constructing a ladder chassis, the connection between cross-members and longitudinal rails is achieved through a combination of bolts and welding. Welding, a process that joins two metal parts using heat generated by gas or electricity, plays a crucial role in chassis fabrication. Different types of weld joints, including butt, lap, corner, T, and edge weld joints, are utilized based on the type and magnitude of the expected load, whether shear or torsional. Safety precautions, such as wearing welding gloves and a protective helmet, are essential to prevent injuries. Cleaning, maintaining a clean workplace free of flammable materials and ensuring the availability of fire extinguishers are crucial safety measures (Muthyala, 2019b, Leelakar and Krishnaraj, 2021).

One commonly used welding technique in chassis construction is resistance spot welding, which is a thermo-electric process. This method generates heat at the connection point between two components by passing an electric current through them for a controlled duration. The resistance between the components and the electrode generates the required heat, causing the metal to melt at the junction. Within seconds, the molten metal solidifies, forming a durable weld joint between the two components. This process ensures the structural integrity and reliability of the chassis, allowing it to withstand various loads and operating conditions encountered during vehicle use (Rajarajan et al., 2022, Jou, 2001, Tanco et al., 2015).

Bolting plays a crucial role in the manufacturing of ladder frame chassis, complementing welding as a method of securing components together. In the construction of a ladder frame chassis, bolts are used to join cross-members and longitudinal rails, providing mechanical strength, and facilitating ease of assembly and disassembly. Unlike welding, which permanently fuses metal parts together through heat, bolting allows for a more modular approach to chassis construction. This modularity enables manufacturers to easily replace or modify chassis components as needed, simplifying maintenance, repairs, and customization (Smith et al., 2006, Prasad U et al., 2020).

The use of bolts in chassis construction offers several advantages. Firstly, it provides flexibility in design and assembly, allowing for rapid prototyping and iteration. Bolted connections can be easily adjusted or repositioned during assembly, ensuring precise alignment and fitment of chassis components. Additionally, bolting allows for the incorporation of removable components, such as body panels or accessory mounts, facilitating accessibility for servicing and upgrades.

2.1 Integration of SEV

Integrating solar panels into the design of SEVs presents opportunities for augmenting onboard energy generation and extending vehicle range. Solar panels can be mounted on various vehicle surfaces, including the roof, hood, and integrated into body panels, maximizing exposure to sunlight. Efficiency considerations, such as panel type, orientation, and tracking systems, influence the amount of energy harvested and its utilization for propulsion or auxiliary systems. Solar panels are typically mounted on the vehicle's surface to capture sunlight and convert it into electrical energy. Advanced battery systems are used to store excess energy generated by solar panels for use during periods of low sunlight or high energy demand (Morais et al., 2015, Mojumder et al., 2022, Bower et al., 2011, Atallah et al., 2016).

Despite the potential benefits of solar power integration, challenges and limitations persist, including limited energy generation capacity, storage constraints, and practicality issues. The intermittent nature of solar irradiance and the limited surface area available for solar panels pose challenges to achieving meaningful energy gains. Moreover, the integration of solar panels adds complexity and cost to vehicle design, raising questions about cost-effectiveness and scalability (Al Shaqsi et al., 2020, Al-Shahri et al., 2021, Castillo and Gayme, 2014).

Battery technology serves as a cornerstone of SEV development, with various options such as lithium-ion, nickel-metal hydride, and solid-state batteries offering different performance characteristics. Advances in battery management systems (BMS) enable precise state-of-charge estimation, thermal management, and cell balancing, enhancing overall battery efficiency and longevity. Ongoing research efforts focus on improving safety, reducing costs, and enhancing sustainability through battery recycling initiatives (Zhao et al., 2021, Fan et al., 2020).

The suspension system plays a critical role in vehicle dynamics, influencing ride comfort, handling, and stability. Various suspension architectures, including independent, semi-independent, and dependent systems, are utilized in SEVs, with material considerations ranging from steel and aluminum to advanced composites. Integration of suspension design with vehicle weight distribution and aerodynamics optimizes overall vehicle performance and efficiency.

Electric motors provide propulsion for the vehicle, delivering power to the wheels efficiently and quietly. Power management systems regulate the flow of energy between the solar panels, battery, motor, and other electrical components, optimizing performance and efficiency. Recent developments in SEV components have focused on improving energy storage capacity, reducing weight, and enhancing overall system reliability (Chan and Wong, 2004, Kumar and Jain, 2014, Cao et al., 2019, Gieras and Bianchi, 2004).

SEVs contribute to reducing greenhouse gas emissions and advancing sustainable transportation goals through their low-carbon footprint and reliance on renewable energy sources. Life cycle assessments highlight the environmental impact of SEVs, from embodied energy and manufacturing emissions to end-of-life disposal considerations. Sustainable materials and manufacturing processes, including the use of recycled materials and eco-friendly techniques, further enhance the environmental sustainability of SEVs, aligning with global efforts to combat climate change and promote sustainable development.

Despite the progress made in solar vehicle technology, several challenges remain to be addressed to realize the full potential of SEVs. Limited range, energy storage capacity, and charging infrastructure are among the most significant barriers to the widespread adoption of SEVs. Additionally, the high cost of solar panels and batteries presents economic challenges for consumers and manufacturers alike.

However, ongoing research efforts aimed at overcoming these challenges offer promising opportunities for the future of SEVs. Advances in battery technology, lightweight materials, and solar panel efficiency are expected to improve the performance and viability of SEVs in the coming years. Furthermore, the environmental and economic benefits of SEVs, including reduced greenhouse gas emissions and long-term cost savings, underscore their potential as a sustainable transportation solution.

CHAPTER 3 : METHODOLOGY

3.1 Method Overview

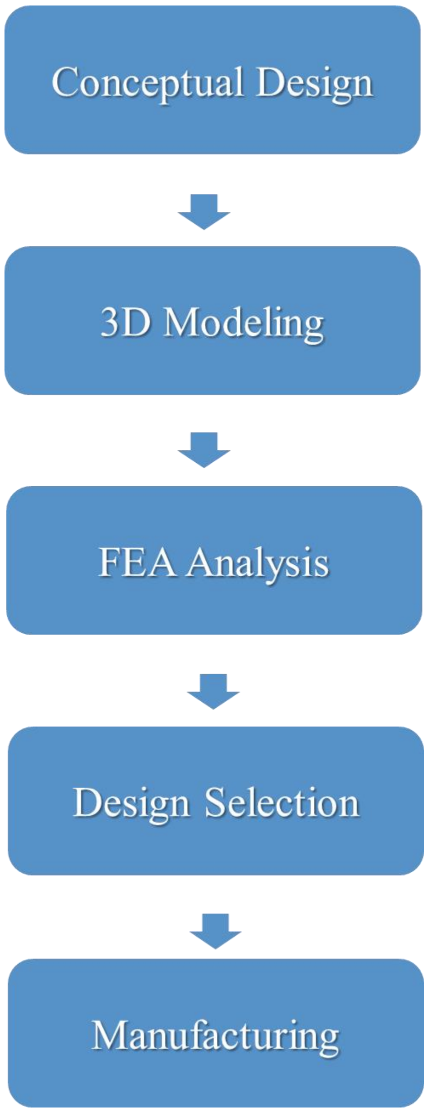

Figure 3.1: Overview of methodology.

3.2 Design Methodology

3.2.1 Design Requirements and Specifications

The design task at hand entails the creation of a four-passenger vehicle with a strict maximum chassis weight limit of 150kg. This limitation is foundational to maintaining the overall vehicle weight within the designated 1000kg threshold, factoring in the weight of passengers, battery pack, and other essential components. The weight of each passenger, estimated between 75-100kg, underscores the importance of integrating these weights into the design process to ensure the vehicle's structural integrity and safe operation.

To uphold safety standards, the chassis must weigh less than 150kg, preventing excessive stress on the vehicle's frame and components. Likewise, the overall vehicle weight should not exceed 450kg to maintain optimal performance and manoeuvrability. Prescribed dimensions, including a maximum length of 3500mm and width under 1500mm, are crucial for meeting regulatory standards and practical usability. The specified wheelbase of 2460mm, mirroring that of the Suzuki Alto 2016 model, ensures stability and compatibility with existing design principles.

A factor of safety (FOS) of 7 or higher is mandated to provide a margin of safety against structural failure under varying operating conditions, prioritizing occupant protection and vehicle durability. Stiffness requirements, with bending and torsional stiffness set at 3 KN/mm and 3 KN/degree respectively, are derived from literature to guarantee adequate rigidity and responsiveness while navigating different road conditions.

Mild steel is chosen as the material for its cost-effectiveness and favorable fatigue strength, striking a balance between performance and affordability. Emphasizing modularity and cost efficiency in the design process facilitates ease of manufacturing, assembly, and maintenance, aligning with industry standards and market demands.

The prescribed speed range of 80-100 km/h corresponds to typical urban and suburban driving conditions, ensuring the vehicle's suitability for everyday use. Detailed specifications for motor power and battery capacity remain implicit but are critical for achieving desired performance metrics and range capabilities.

Finally, the requirement for the chassis cross-sectional shape to have a moment of inertia equal to or greater than 4652167mm^4 drives exploration into various design configurations, including circular, square, rectangle, and C-section chassis. This criterion influences structural integrity and weight distribution, influencing vehicle dynamics and handling characteristics.

3.2.2 Moment of Inertia

To effectively withstand transverse and lateral loads, it's crucial for the beam to possess a significant moment of resistance. This resistance factor is intricately linked to the moment of inertia, which essentially measures the beam's ability to resist bending under load. A higher moment of inertia signifies a greater resistance to loading forces. To discern which cross-section offers the highest resistance, a calculation of the moment of inertia for each cross-sectional shape with equal areas is required. This analysis helps in selecting the most structurally sound option for the given application.

Moment of inertia for all hollow square cross sections:

$$I = (a_0^4 - a_i^4)/12$$

- a_0 is the outer width of the square tube (the outer side length of the outer square).
- a_i is the inner width of the square tube (the outer side length of the inner square).

Moment of inertia for all c section:

$$I = (bh^3 - (b-t_f).(h-t_w)^3)/3$$

- b is the overall width of the C-section.
- h is the overall height of the C-section.
- t_f is the thickness of the flange.
- t_w is the thickness of the web.

Moment of inertia for all hollow circular cross section:

$$I = pi.\,(D_0^4 - D_i^4)/12$$

- D_0 is the outer width of the square tube (the outer side length of the outer square).
- D_i is the inner width of the square tube (the outer side length of the inner square).

$I = ((b_1 h_1^3 - b_2 h_2^3)/12) + A_1 d_1^2 + A_2 d_2^2$

- b_1 and b_2 are the widths of the top and bottom flanges, respectively.
- h_1 and h_2 are the heights of the top and bottom flanges, respectively.
- A_1 and A_2 are the areas of the top and bottom flanges, respectively.
- d_1 and d_2 are the distances from the centroid of the section to the centroid of the top and bottom flanges, respectively.

According to these formulas, the following dimensions are selected for the initial designs of all chassis.

i. **Square Cross-Section (Chassis no. 1):**
   - This cross-section is characterized by equal sides, resulting in a square shape.
   - The total length and width of this cross-section are 3430 mm and 1500 mm, respectively.
   - The moment of inertia, a measure of an object's resistance to changes in rotation, is calculated as 4933660 mm^4.
   - The thickness of this cross-section is 5 mm.
   - The section height and width are both 120 mm.

ii. **C-section Cross-Section (Chassis no. 2):**
   - This cross-section resembles the letter 'C' and is commonly used in structural applications.
   - The total length and width of this cross-section are 3363 mm and 1494 mm, respectively.
   - The moment of inertia for this cross-section is 4757160 mm^4.
   - It has a thickness of 6 mm.
   - The section height and width are 150 mm and 55 mm, respectively.

iii. **Circular Cross-Section (Chassis no. 3):**
   - This cross-section is circular in shape.
   - The total length and width of this cross-section are 3375 mm and 1445 mm, respectively.
   - The moment of inertia is calculated as 4797340 mm^4.
   - It has a thickness of 7.5 mm.
   - The section height (diameter) is 125 mm, and the width is 111 mm.

iv. Rectangular Cross-Section (Chassis no. 4):

- This cross-section is characterized by unequal sides forming a rectangle.
- The total length and width of this cross-section are 3394 mm and 1505 mm, respectively.
- The moment of inertia for this cross-section is 4860160 mm^4.
- It has a thickness of 4.8 mm.
- The section height is 150 mm, and the width is 96 mm.

After the initial design phase, the final selection of the chassis cross-section will be determined based on a combination of factors including weight and Factor of Safety (FOS).

Factor of Safety (FOS) is a measure used to account for uncertainties in materials, manufacturing, and loading conditions. It represents the ratio of the maximum load a component can withstand to the maximum load it is expected to experience during normal operation. A Factor of Safety greater than 7 indicates a sufficient margin of safety for the chassis design.

Once the initial designs are completed, Computer-Aided Design (CAD) modeling and Finite Element Analysis (FEA) will be conducted. CAD modeling will allow for the creation of detailed digital representations of the chassis designs, while FEA analysis will simulate real-world conditions and assess the structural performance of each design under various loads and operating conditions.

During the FEA analysis, factors such as stress distribution, deformation, and overall structural integrity will be evaluated. The final design will be selected based on achieving the lowest weight while maintaining a Factor of Safety greater than 7.

This approach ensures that the selected chassis design not only meets the required structural strength and performance criteria but also optimizes weight to enhance efficiency and performance in its intended application.

3.2.3 Cross Members

The chassis's longitudinal rails are interconnected via cross-members, which play a pivotal role in supporting vital components like the engine, transmission system, suspension system, and axles. These cross-members also contribute significantly to the chassis's rigidity. While conventional design norms propose that integrating more cross-members can bolster the chassis's durability, it's essential to place them thoughtfully. Random placement won't suffice; strategic positioning is key to minimizing stress and displacement. Furthermore, optimizing the cross-members' design to boost rigidity is crucial for effectively withstanding loads and mitigating stress and displacement.

Proper positioning of each cross-member is paramount to ensure uniform stress and displacement reduction across the chassis while maintaining sufficient stiffness to enhance overall performance. It's critical to keep the cross-members' thickness less than that of the longitudinal rails to prevent issues such as strains at connection points and structural deformations.

The design of a ladder chassis incorporates specific elements:

1) The front end is designed to be narrow to facilitate better steering lock and enhance the turning radius.
2) The rear end is broader and slightly elevated to accommodate rear axle movement, particularly on uneven terrain.
3) The longitudinal rails are inwardly bent at both ends to allow for wheel movement.

Various types of cross-members, including C-type sections, tubular sections, hat sections, box sections, and stamped pressed sections, can be utilized based on the required strength at different locations. Through iterative design iterations, the optimal positions for cross-members are determined, followed by necessary adjustments to enhance strength, such as altering thickness or reshaping. In instances where increasing thickness poses challenges, additional supports are provided to the cross-members.

3.3 CAD Model

3.3.1 Cad model of chassis

The initial designs are modelled in accordance with the initial calculations and design criteria. Cross members are selected and modelled based on their suitability for the chassis. SolidWorks is employed for 3D modelling purposes. These models will subsequently undergo Finite Element Analysis (FEA) to evaluate their structural integrity and performance, ultimately informing the final design of the chassis.

i. Square Cross-Section (Chassis no. 1):

This square cross-section measures 3430 mm in length and 1500 mm in width, with a thickness of 5 mm. It has a section height and width of 120 mm. The moment of inertia is calculated at 4933660 mm^4, indicating its resistance to rotational changes.

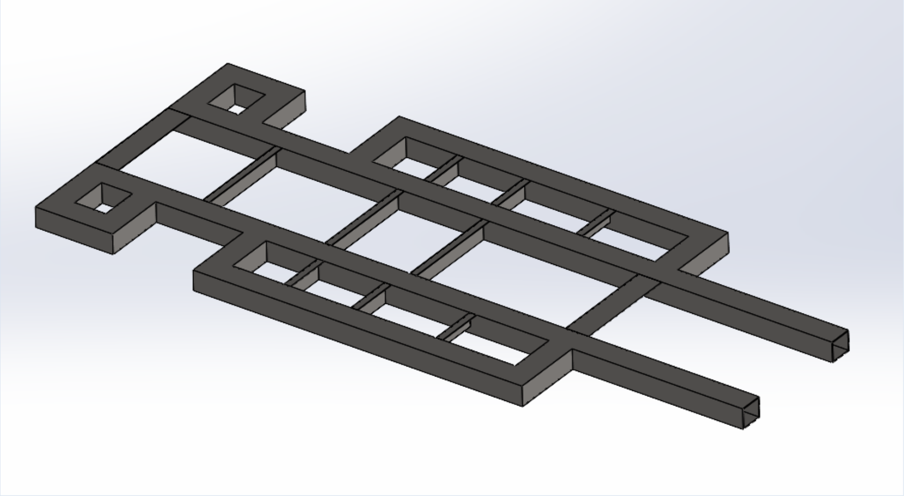

Figure 3.2: 3D CAD model of Square Cross Section Chassis

ii. C-section Cross-Section (Chassis no. 2):

This 'C' shaped cross-section, commonly used in structural applications, measures 3363 mm in length and 1494 mm in width, with a thickness of 6 mm. It has a section height of 150 mm and a width of 55 mm. The moment of inertia for this cross-section is 4757160 mm^4, indicating its resistance to rotational changes.

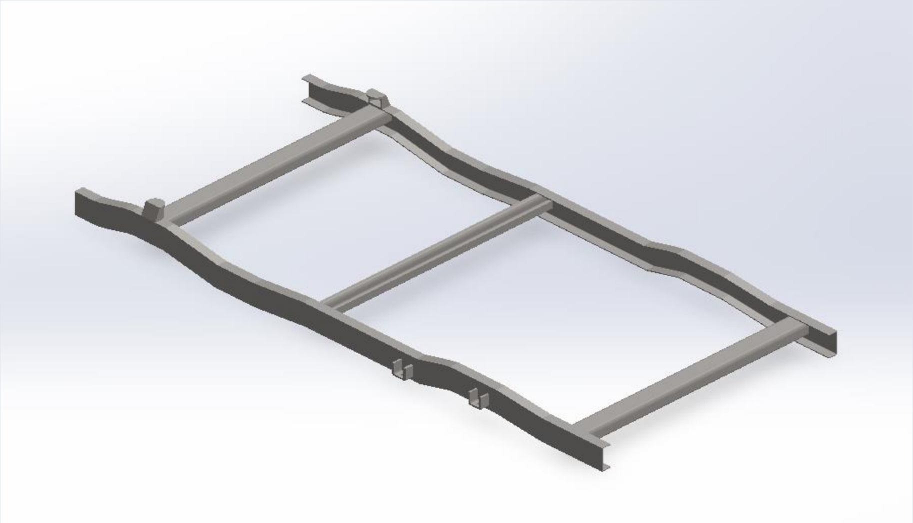

Figure 3.3: 3D CAD model of C-Section Cross Section Chassis

iii. Circular Cross-Section (Chassis no. 3):

This circular cross-section, measuring 3375 mm in length and 1445 mm in width, features a thickness of 7.5 mm. Its section height, or diameter, is 125 mm, and the width is 111 mm. The moment of inertia is calculated at 4797340 mm^4, indicating its resistance to rotational changes.

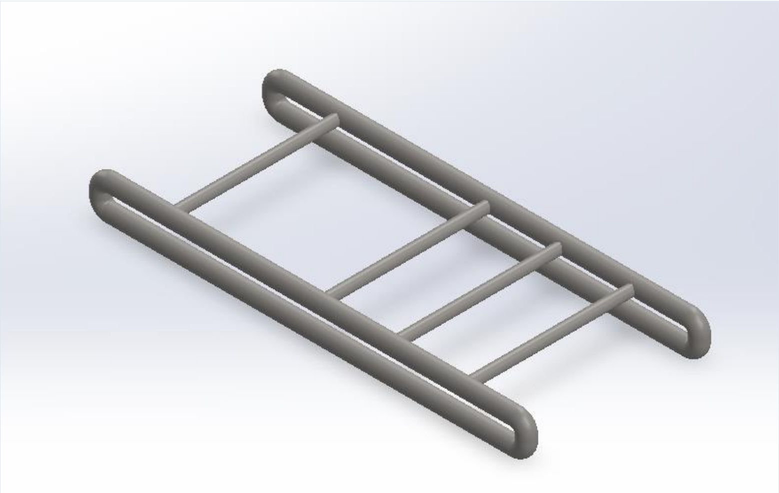

Figure 3.4: 3D CAD model of Circular Cross Section Chassis

iv. Rectangular Cross-Section (Chassis no. 4):

This rectangular cross-section, featuring unequal sides, measures 3394 mm in length and 1505 mm in width, with a thickness of 4.8 mm. Its section height is 150 mm, and the width is 96 mm. The moment of inertia for this cross-section is calculated at 4860160 mm^4, indicating its resistance to rotational changes.

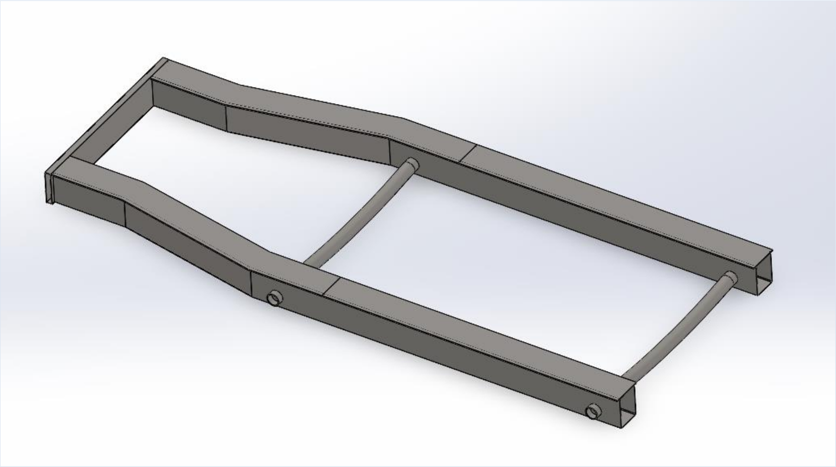

Figure 3.5: 3D CAD model of Rectangular Cross Section Chassis

3.4 FEA Analysis

The SolidWorks-designed CAD model of the ladder chassis undergoes Finite Element Analysis (FEA). To streamline the process, unnecessary fillets and holes are removed from the CAD model, reducing computational time. The simplified model is then imported into Ansys software for FEA.

3.4.1 Meshing:

Meshing is a critical operation in the realm of Finite Element Analysis (FEA), involving the meticulous subdivision of the Finite Element model into smaller, well-organized elements. Within this context, the process of meshing the chassis assumes significant importance, given its direct correlation to the precision and reliability of FEA outcomes. To ensure the utmost accuracy in meshing and subsequently in FEA results, it is imperative to uphold stringent quality standards, encompassing parameters such as warpage, Jacobian, aspect ratio, and skew ratio.

Considering the diverse geometric complexities inherent in chassis design, tailored meshing methods are employed to address each unique cross-sectional configuration. Across all meshes, a quadratic element order is uniformly adopted to maintain consistency and accuracy. Furthermore, an automated approach is integrated into the fabrication process, specifically for rectangular cross members, ensuring a standardized mesh size of 20mm.

In the pursuit of dependable analysis, the Tetrahedron technique emerges as the preferred methodology for both chassis and cross members alike, characterized by its effective utilization of a 20mm element size. This comprehensive approach not only underscores the meticulousness required in meshing operations but also highlights the commitment to achieving precise and reliable FEA results within the realm of chassis engineering.

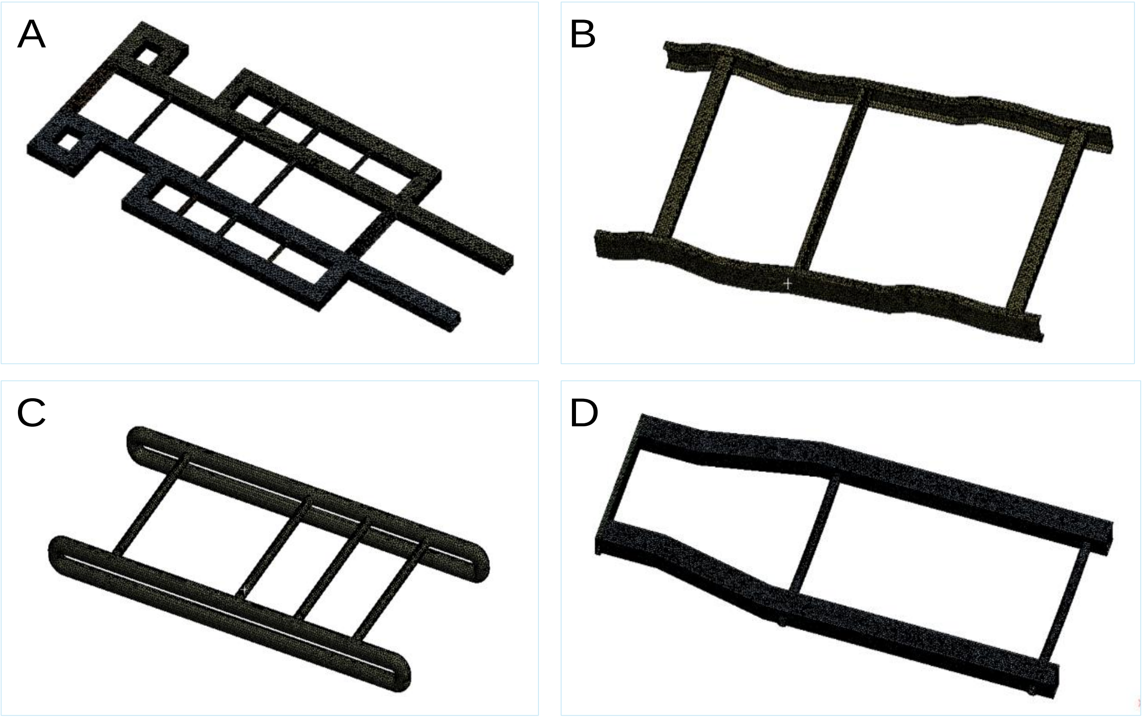

Figure 3.6: Meshing of chassis A) Rectangular, B) c section, C) circular, and D) rectangular.

3.4.2 Material Properties:

In crafting this chassis model, steel is chosen for its robustness, with longitudinal rails, brackets, and cross-members all fashioned from this durable material. Within Ansys, each component is meticulously assigned mechanical properties sourced from the following Table 3.1.

Table 3.1: Material Properties of Steel

Property	**Values**
Density	7850 kg/m3
Young's Modulus	2e+05 MPa
Poisson's ratio	0.3
Tensile Yield Strength	200 MPa
Tensile Ultimate Strength	460 MPa

3.4.3 Torsional Stiffness

Considering the real-world setup, loads and boundary conditions are carefully factored in. These conditions are structured to induce twisting in the chassis. Typically, loads are applied to the axle in reality. However, for Finite Element Analysis (FEA), loads are positioned at corresponding locations along the longitudinal rails instead of directly on the axle. To induce chassis twist, positive and negative forces are applied at the front end, while the rear end of the chassis is fully constrained, preventing any movement in translation or rotation. This mirrors real-world loading conditions within the FEA environment.

Enhancing the vehicle's handling necessitates greater torsional stiffness, especially crucial for navigating uneven terrain and pothole-ridden roads. To calculate torsional stiffness, the total Gross Vehicle Weight (GVW) is selected as the load applied to the chassis, typically 800 kgs. GVW represents the maximum load capacity of the vehicle. Thus, to achieve a stiffer chassis, the load applied is equivalent to the GVW. Therefore, the load acting on the chassis for torsional loading equals 800 kg, or 8000 N. Distributing this load evenly, each longitudinal rail bears a force of 4000 N.

All the initially designed chassis are gone through an analysis for torsional stiffness and the directional displacements are measured accordingly as shown in figure:

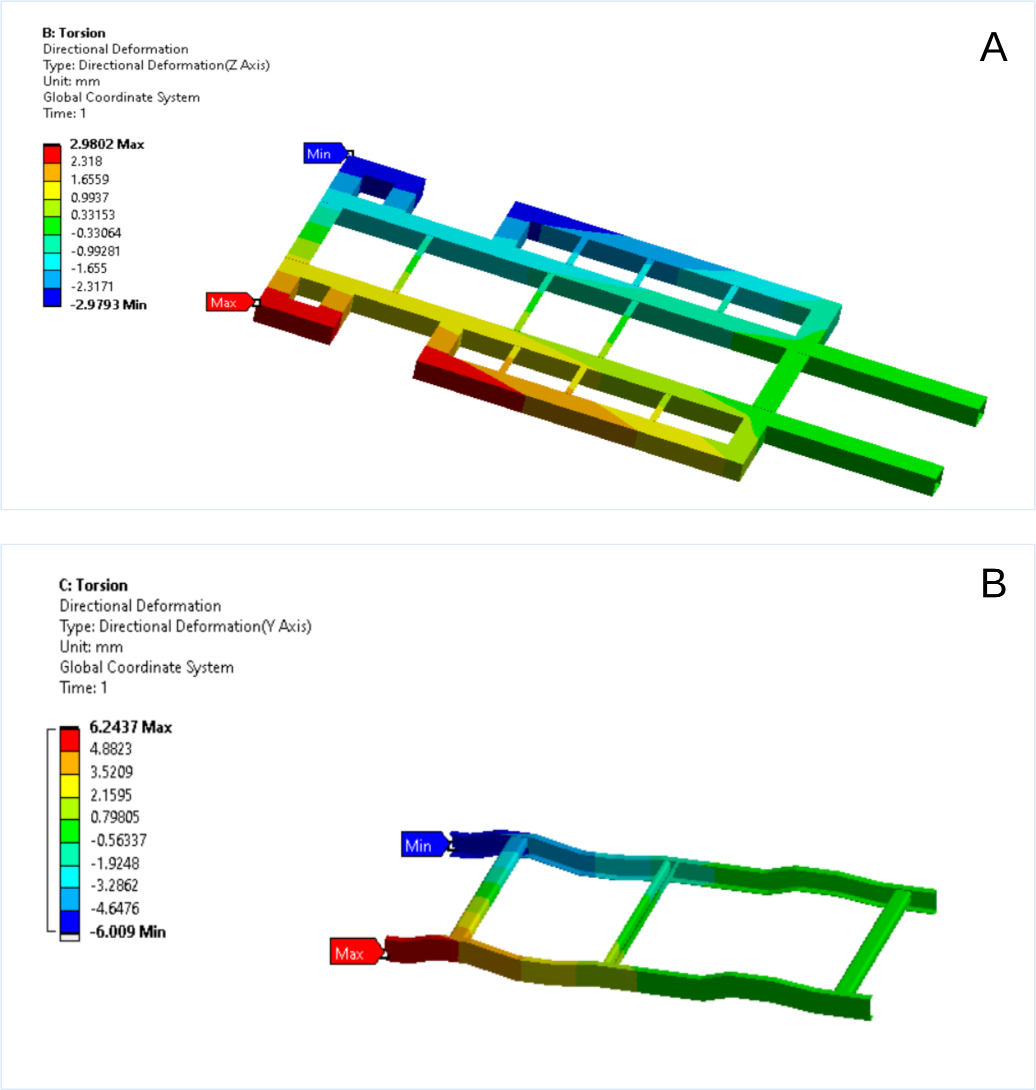

Figure 3.7: Torsional displacement for A) square section and c-section B).

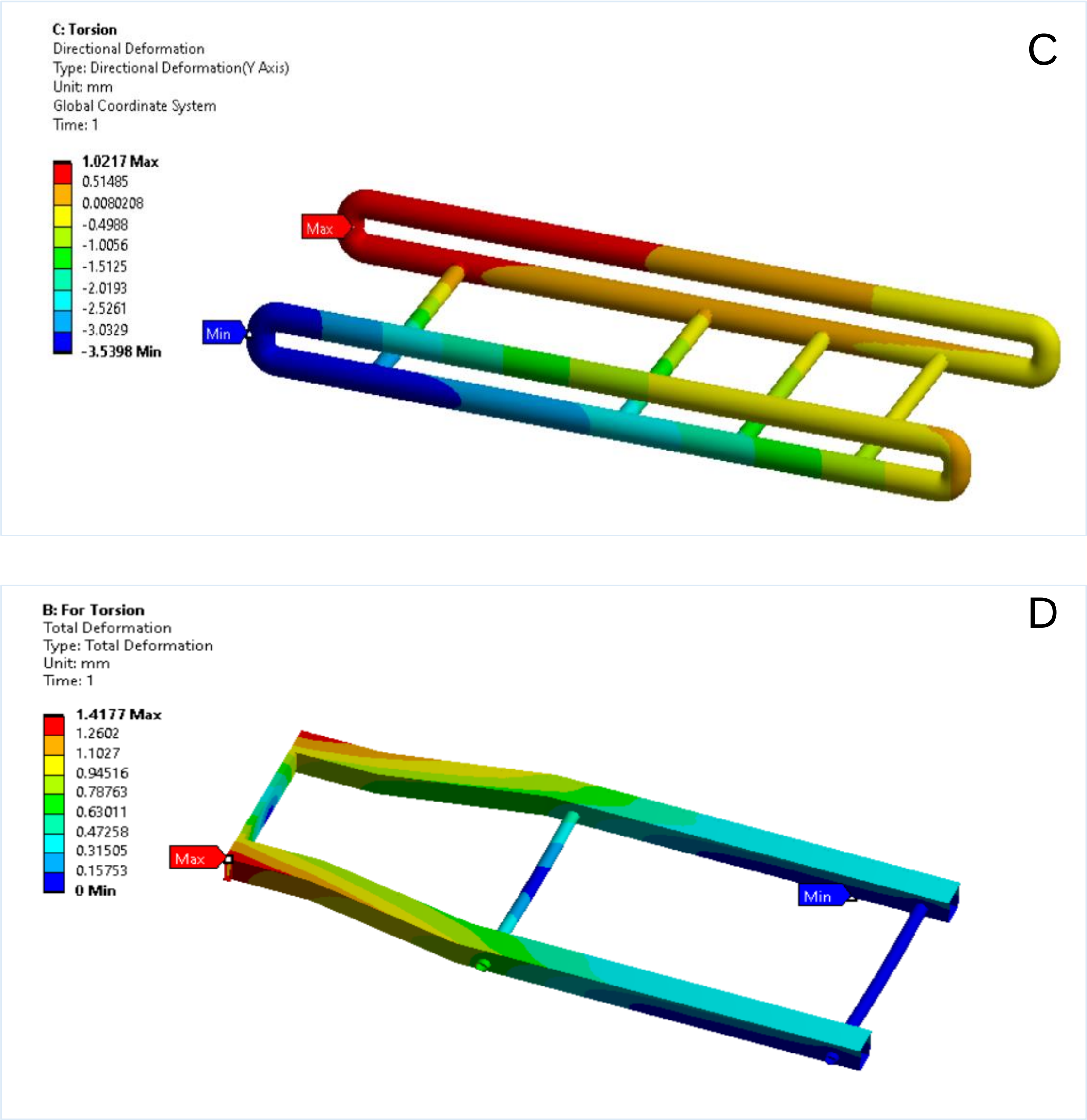

Figure 3.8: C) Circular Section, and D) Rectangular Section

All chassis designs passed the initial torsional stiffness test, exceeding the minimum requirement of 3kN-m/deg as can be seen in the table. However, weight is now the primary factor for selecting the final design. The acceptance criteria specify a maximum weight of 150 kg for the entire chassis.

Table 3.2: Torsional Stiffness of all chassis type

Chassis no.	Type of Cross Section	Displacement (mm)	Angel (degrees)	Torsion (kNm)	K (kNm/deg)
1	Square	2.9802	0.294401526	2320	7.880
2	C-section	6.2437	0.514730453	2780	5.401
3	Circular	1.0217	0.097973387	2390	24.394
4	Rectangular	1.3483	0.285589282	1082	3.789

Table 3.3: Weight of all chassis type

Chassis no.	Type of Cross Section	Weight (kg)
1	Square	245
2	C-section	479
3	Circular	456
4	Rectangular	92

Considering steel as the material, the weight analysis of each chassis design reveals that only the rectangular chassis meets the weight requirement. Therefore, the rectangular chassis is chosen for further evaluation and will undergo bending stiffness testing.

1.1 Bending Stiffness:

i. Boundary conditions and loads for bending stiffness

To determine the bending stiffness of a rectangular chassis, it is simulated in real-world conditions in which the chassis is subjected to bending forces. In this scenario, they secure both the front and rear ends of the chassis to restrict any movement in all directions (X, Y, Z-axis), ensuring a stable reference frame. Next, a bending load is applied to the chassis. In this case, the load is applied at the center of both longitudinal rails, which are the long beams running the length of the chassis. This load mimics the weight or payload that the chassis might carry during operation, in this instance specified as 800 kg or 8000 N.

Since the load is evenly distributed between the two longitudinal rails, each rail carries half of the total load, resulting in 4000 N per rail. This distributed load induces bending stresses within the chassis structure.

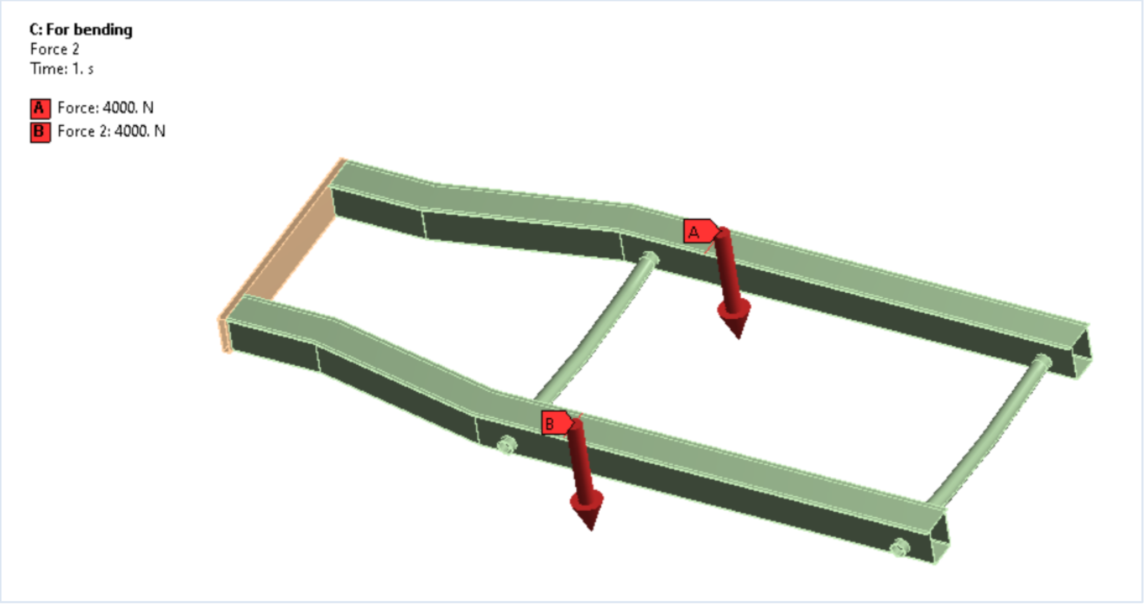

Figure 3.9: Bending Load Applied on Chassis

An analysis of bending under uniformly distributed load is conducted on the chassis, with the payload weight applied to the main rails. The objective is to achieve a safety factor exceeding 7 as per acceptance criteria.

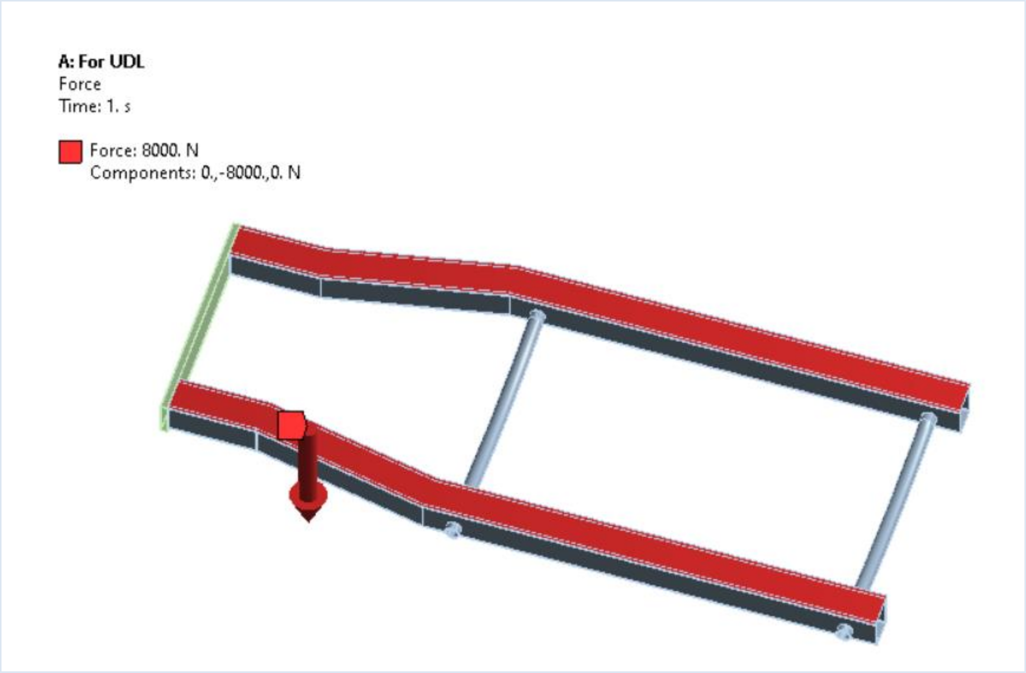

Figure 3.10: Uniformly Distributed Load Applied on Chassis

ii. Results from Bending Stiffness Analysis:

For uniformly distributed loading, the factor of safety exceeds 7, resulting in safe chassis:

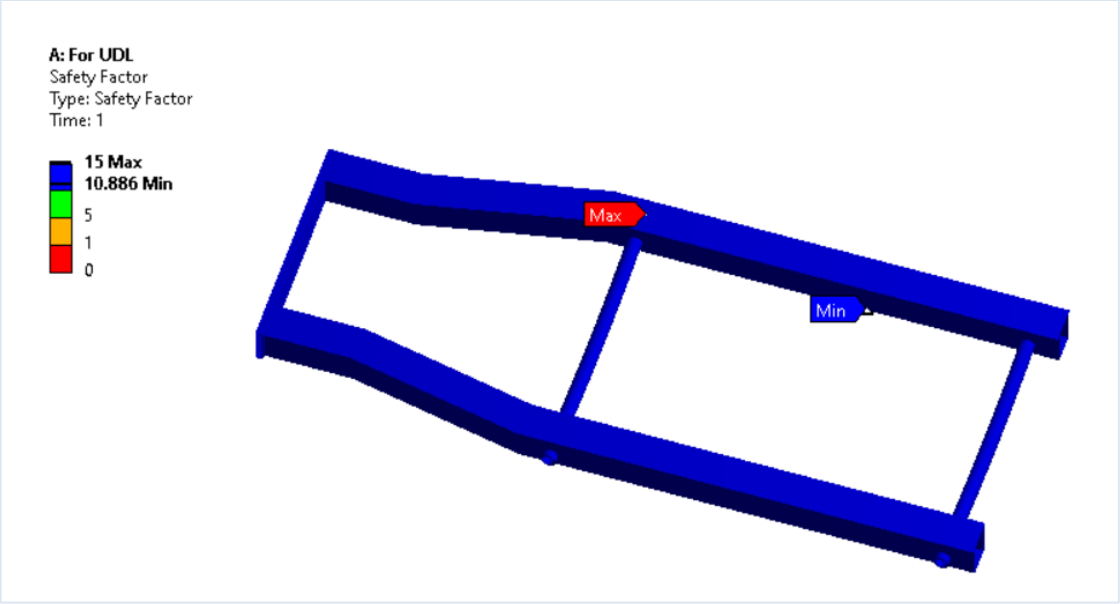

Figure 3.11: FOS for Uniformly Distributed Load

The displacement for the bending stiffness condition is depicted in the figure. The obtained displacement value, 1.0197 mm, represents how much the chassis deforms or bends when subjected to the specified load. To calculate the bending stiffness from this displacement, the following formula is utilized:

Bending Stiffness = 4000/1.0197 = 3922.722 N/mm = 3.922 kN/mm

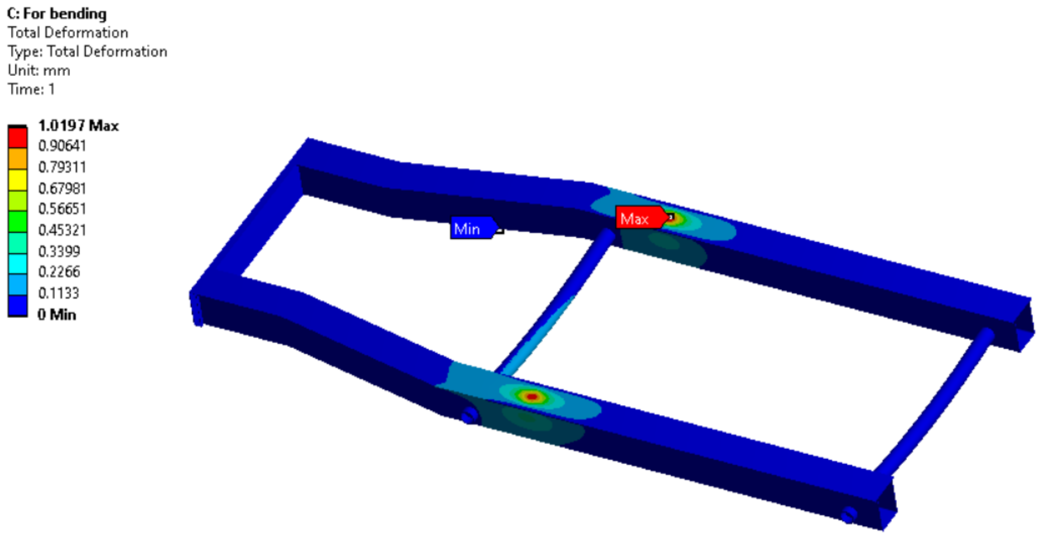

Figure 3.12: Displacement for Bending Stiffness

The stress distribution obtained for this specific loading condition is depicted in Figure, showcasing a stress value of 314.81 MPa under the bending loading. Upon analyzing the obtained value of bending stiffness, it surpasses the predefined acceptance criteria. Consequently, this design meets the required standards regarding bending stiffness. As a result, rectangular chassis, utilizing steel material, is confirmed as the final choice for this application.

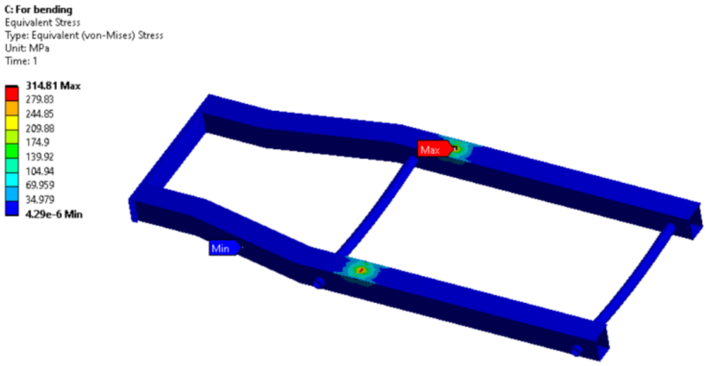

Figure 3.13: Equivalent Stress for Bending Stiffness

3.5 Final Design

This chapter delves into the culmination of the design journey – the finalized chassis and its integrated components. Through meticulous analysis, iterative refinement, and innovative thinking, a design that embodies both performance and practicality has been selected. This chapter provides a comprehensive overview of the chassis design, along with the integration of essential components such as the front and rear suspension systems, transmission, motor, steering system, and more.

- **Front Suspension:**

Integration of the front suspension system into the chassis was a critical aspect of the design process, impacting both vehicle performance and handling characteristics. The chosen front suspension configuration, a double wishbone system, was carefully integrated to optimize weight distribution and enhance dynamic responsiveness. The double wishbone suspension components were strategically positioned within the chassis to achieve optimal alignment and geometry. By carefully considering factors such as caster angle, camber angle, and kingpin inclination, the team ensured precise handling and stability under varying driving conditions. Additionally, the integration of the front suspension components was designed to minimize unsprung mass, improving overall ride quality and responsiveness.

Figure 3.14: Front Suspension

- **Rear Suspension**

The incorporation of a leaf spring suspension system at the rear of the vehicle was a deliberate choice to balance performance, durability, and cost-effectiveness. This traditional suspension design offers simplicity in construction while providing sufficient load-bearing capacity and stability, making it suitable for a wide range of applications. The leaf spring assembly was carefully positioned and mounted within the chassis to optimize load distribution and suspension geometry. The spring mounts were strategically placed to ensure proper alignment and articulation, allowing the leaf springs to flex and absorb road irregularities effectively. Additionally, the rear axle was positioned to align with the leaf springs, ensuring optimal weight distribution and load transfer during acceleration, braking, and cornering maneuvers.

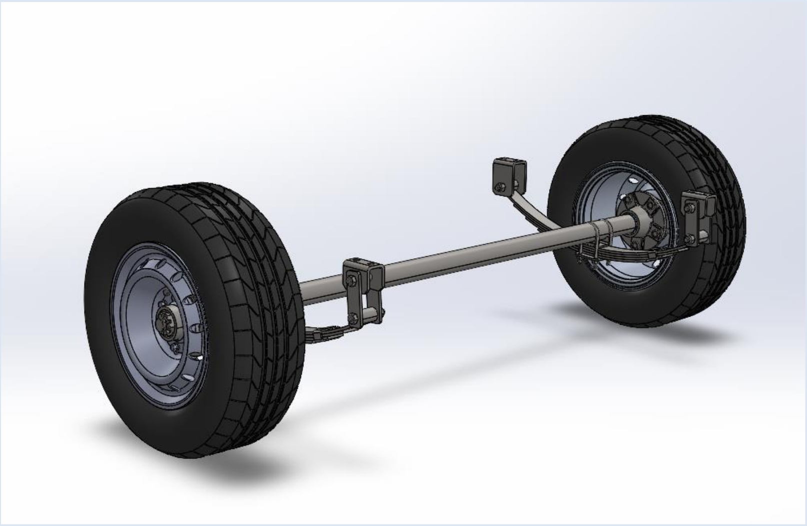

Figure 3.15: Rear Suspension

- **Steering System:**

The integration of the steering system into the chassis is fundamental to the vehicle's maneuverability and driver control. The chosen steering system, typically a rack and pinion setup, is meticulously integrated to provide precise steering input and responsiveness. The steering rack, along with associated components such as tie rods and steering linkages, is strategically positioned within the chassis to optimize driver ergonomics and vehicle dynamics. The steering column is securely mounted to the chassis, providing a direct connection between the driver's input and the vehicle's front wheels. Proper alignment and connection ensure that steering inputs are translated accurately into vehicle movement, enhancing driver confidence and control.

Figure 3.16: Steering System

- **Transmission and motor system:**

The integration of the transmission and motor system into the chassis is pivotal in ensuring optimal power delivery, efficiency, and overall performance of the vehicle. This section explores how these components are seamlessly integrated to drive the vehicle's propulsion. The transmission and motor assembly are strategically positioned within the chassis to optimize weight distribution and drivetrain efficiency. Typically, the transmission is mounted directly to the engine block or positioned adjacent to it, while the electric motor may be located at various points along the chassis, depending on the vehicle's layout. Proper alignment and mounting ensure that power is transmitted efficiently from the motor to the wheels, maximizing traction and performance. The transmission serves as the interface between the motor and the drivetrain, converting the motor's rotational energy into forward or reverse motion. Depending on the vehicle's configuration, the transmission may be coupled to the motor via a direct drive system or through a gearbox with multiple gear ratios. The integration of the transmission and motor into the drivetrain ensures smooth power delivery across various driving conditions, optimizing acceleration, efficiency, and top speed.

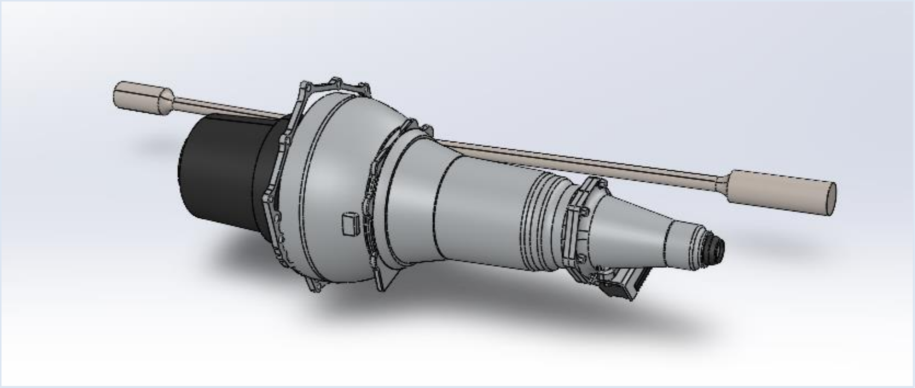

Figure 3.17: Transmission and motor system.

- **Final Assembly**

The fully assembled model represents the culmination of meticulous design and integration efforts, where every component comes together harmoniously to form a cohesive and functional vehicle. The chassis serves as the structural backbone, accommodating components such as suspension systems, transmission, motor, and steering system, ensuring optimal performance and safety. Integrated front and rear suspension systems provide stability and ride comfort, while the transmission and motor system deliver smooth and responsive propulsion. The steering system enables precise control, while seats and gear knob enhance comfort and driving experience. Overall, the fully assembled model embodies innovation, functionality, and driver satisfaction through careful design and integration.

Figure 3.18: Final Assembly

3.6 Manufacturing of Solar Electric Vehicle

The manufacturing of the chassis for the solar electric vehicle in Pakistan commenced following the final selection of chassis based on initial research and market survey findings. This section outlines the detailed steps involved in the fabrication process, emphasizing the rationale behind the chosen techniques and materials.

3.6.1 Material Selection and Market Survey:

At the outset of the research, a thorough market survey was conducted to identify locally available materials suitable for chassis construction. Factors such as material availability, cost-effectiveness, and mechanical properties were carefully assessed. Based on this survey and preliminary research, high-strength steel emerged as the optimal choice for its affordability and widespread availability in the local market. The required materials were procured from trusted suppliers with a focus on quality and reliability.

3.6.2 Cutting and Shaping

The steel sheets were cut and shaped using basic cutting tools to match the dimensions specified in the finalized design. Precision was maintained through manual measurement and cutting techniques to ensure proper fitment during assembly.

3.6.3 Assembly:

In the meticulous assembly of the chassis components, a deliberate selection process guided the choice of assembly techniques. Drawing upon a wealth of expertise and industry best practices, a combination of nuts, bolts, and spot-welding techniques was meticulously chosen. Skilled craftsmen meticulously executed the assembly process, ensuring precision and reliability at every stage.

The integration of a DC controller paired with a robust 7.5KW motor marked a pivotal step in the vehicle's propulsion system. Through meticulous engineering, the motor was seamlessly integrated into the transmission system, facilitated by a carefully engineered coupler plate. To mitigate potential sources of instability, the motor was securely affixed in place with the aid of vibration fixtures, ensuring minimal vibration during operation.

This selection of assembly techniques and propulsion components was informed by a comprehensive evaluation of various factors. Considerations such as structural integrity, performance optimization, and operational efficiency were meticulously weighed, guiding the decision-making process. By prioritizing reliability, functionality, and adherence to industry standards, the chosen assembly methods and propulsion system configuration lay a solid foundation for the vehicle's performance and longevity.

- Accessibility and Cost: Nuts, bolts, and spot-welding equipment are readily available in local markets and are cost-effective compared to more specialized assembly methods.
- Ease of Assembly: Nuts and bolts offer flexibility during assembly, allowing for adjustments and disassembly if needed. Spot welding provides a quick and efficient means of joining metal components, particularly suitable for large-scale production.
- Strength and Durability: When properly executed, nuts, bolts, and spot welding create strong and durable joints, essential for ensuring the structural integrity of the chassis under dynamic loads.

3.6.4 Quality Assurance:

Throughout the assembly process, quality control checks were conducted to verify the integrity and dimensional accuracy of the chassis. Visual inspections and measurements were performed to identify any defects or inconsistencies, ensuring compliance with design specifications.

3.6.5 Integration with Vehicle Components:

Upon completion of the chassis, it was integrated with all the necessary components required for the solar electric vehicle. This included mounting points for the battery pack, motor, suspension system, and other vital components essential for vehicle operation.

3.6.6 Testing and Validation:

Upon completion of its assembly, the solar electric vehicle underwent a series of exhaustive tests to validate its performance and functionality. Methodical road tests were conducted to assess the vehicle's handling, stability, and overall operational capabilities. Adherence to stringent acceptance criteria, notably including achieving and sustaining a speed of 100 kilometers per hour, affirmed its readiness for road use.

Additionally, a rigorous load test was implemented to evaluate the structural integrity of the vehicle's chassis under realistic conditions. By subjecting the chassis to an 800-kilogram load, meticulous observations were made to detect any signs of bending or deformation. The results demonstrated that the vehicle's chassis remained within the allowable range of deformation, confirming its durability and reliability under significant loads.

These thorough testing procedures underscore not only the engineering excellence of the solar electric vehicle but also its preparedness for real-world deployment. Through meticulous adherence to performance benchmarks and structural integrity standards, the vehicle stands as a testament to technological innovation, poised to navigate diverse road conditions with confidence and efficiency.

Figure 3.19: Testing and Validation

Figure 3.19: Final Assembly

Above is the final assembly of the solar electric vehicle with all of its components assembled on the ladder frame chassis, i.e., controller, motor, mountings, transmission system, steering system, tires with rim, suspension system, lithium ion battery pack, and seats.

CHAPTER 4 : DISCUSSION AND CONCLUSION

The culmination of this study marks the successful realization of the objectives set forth at its inception. Through a comprehensive literature survey, types of chassis frames, their stiffness characteristics, and suitable materials for solar electric vehicles were meticulously examined, providing a robust foundation for subsequent design and analysis.

Employing computer-aided drafting (CAD) software SolidWorks, multiple iterations of the ladder frame chassis were generated and evaluated against stringent acceptance criteria. Finite element analysis (FEA) served as a critical tool in refining chassis designs, ensuring compliance with key parameters such as weight, strength, and stiffness. The iterative design process culminated in the selection of the final chassis design, which met all acceptance criteria while optimizing weight through FEA-driven iterations. The chosen ladder frame chassis design successfully met the specified acceptance criteria, including modularity for weight distribution, a target gross weight under 150kg, and factors of safety (FOS) exceeding 7. Additionally, the bending stiffness surpassed 3KN/mm, while torsional stiffness exceeded 3KN/deg, ensuring structural robustness and performance. The total vehicle weight remained under the prescribed 450kg limit, further validating the design's efficiency and effectiveness.

Propulsion of the solar electric vehicle (SEV) is provided by electric batteries supplemented by solar energy, aligning with the specified capacity for sustainability and environmental consciousness. The SEV comfortably accommodates four passengers while boasting a maximum speed of 100 km/h, meeting performance expectations without compromising safety or efficiency. The integration of all components, including the manufactured ladder frame chassis, marks a significant milestone in the realization of the SEV. By translating theoretical concepts into tangible results, this study underscores the practical viability and real-world applicability of the designed chassis.

Looking ahead, further refinement and optimization may be pursued to enhance the SEV's efficiency, performance, and cost-effectiveness. Continued research into advanced materials, component arrangements, and performance evaluations promises to further elevate the SEV's position as a sustainable transportation solution for the future.

Research into electric vehicle (EV) chassis development in Pakistan serves as a cornerstone of knowledge, offering invaluable insights within the parameters of its defined scope. However, it is paramount to acknowledge the boundaries of this research endeavor. While commendable progress has been achieved in conducting crash analysis, the pursuit of vehicular safety mandates a more expansive exploration encompassing diverse collision scenarios. Only through such comprehensive simulations can we ensure the robustness of passenger safety measures and uphold stringent regulatory standards.

At the core of the study lies a meticulous examination of welded joints between chassis components—a pivotal nexus where theoretical engineering principles intersect with practical realities. Yet, as we endeavor to push the boundaries of knowledge forward, we are confronted with the intricate complexities inherent in real-world applications. Real-world welded joints embody a tapestry of challenges, characterized by stress concentrations and potential failure points. Addressing these complexities requires a concerted effort involving empirical validation and the deployment of advanced simulation methodologies.

Looking towards the future, the vista expands, beckoning us to bridge the gap between theory and application. Real-world testing emerges as a beacon of validation, shedding light on the efficacy of theoretical constructs in the crucible of practical conditions. As we navigate this terrain, collaboration emerges as a linchpin of progress—a harmonious collaboration between engineers, designers, and policymakers. Together, they orchestrate a symphony of innovation, ensuring that the chassis design borne from this endeavor seamlessly aligns with market demands, regulatory imperatives, and manufacturing capabilities in Pakistan.

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