DESIGN AND STRUCTURAL ANALYSIS OF AN ELECTRIC GARBAGE COLLECTION VEHICLE CHASSIS AND CARGO BOX

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Abstract

This study presents the structural analysis and redesign of the chassis and cargo box of an electric garbage collection vehicle using finite element analysis in ANSYS Workbench. Three-dimensional CAD models were developed and analysed under static loading conditions to evaluate equivalent stress and total deformation. Mild Steel was considered as the existing material, while Aluminium Alloy 6061-T6, AISI 4130 steel, ASTM A710 steel, and Stainless Steel 304L were evaluated for comparative structural assessment. The existing design was first analysed and subsequently compared with the redesigned configuration. The chassis was redesigned by reducing the thickness of selected non-critical members to improve payload capacity and vehicle efficiency. Similarly, selected regions of the cargo box were modified to represent corrosion-induced thickness reduction under municipal solid waste operating conditions. Static structural analysis was performed under actual service loading conditions.

Based on the comparative structural analysis, ASTM A710 steel was identified as the most suitable material for the redesigned structures. The redesigned chassis showed a maximum equivalent stress of 76.186 MPa, a total deformation of 0.14366 mm, and a structural weight of 45.850 kg. The redesigned cargo box exhibited a maximum equivalent stress of 177.09 MPa, a total deformation of 1.0459 mm, and a structural weight of 97.442 kg. The obtained results confirmed that the redesigned chassis and cargo box satisfied the required structural performance while achieving the intended weight reduction for electric garbage collection vehicle applications. Although stress and deformation increased slightly after redesign, all values remained within the allowable limits of the material. The findings indicate that ASTM A710 steel provides an effective balance between structural safety, weight reduction, and durability, making it a suitable material for electric garbage collection vehicle applications.

Keywords: Electric Garbage Collection vehicle; Chassis; Cargo box; Finite element analysis

Introduction

Rapid urbanization and the continuous increase in municipal solid waste generation have created a growing demand for efficient electric garbage collection vehicles for urban waste management. The structural performance of the chassis and cargo box is essential for ensuring vehicle safety, durability, load-carrying capacity, and long-term operational reliability. The chassis supports major vehicle components such as the battery pack, motor assembly, suspension system, and cargo box, whereas the cargo box is continuously subjected to waste loading, moisture, and corrosive environmental conditions. These operating conditions may lead to stress concentration, deformation, and corrosion-induced material degradation, affecting the overall structural performance of the vehicle.

The study investigates chassis weight reduction through cross-section modification using finite element analysis. The optimized design achieves lower weight while maintaining safe stress and deformation limits. [1] This study optimized a tipper truck body using finite element analysis by comparing different design models. The optimized design reduced weight while maintaining safe structural performance and improving payload capacity [2] The paper compares different alloy materials and cross-sections for a heavy vehicle chassis using FEA. It concludes that material selection significantly influences stress, deformation, and structural performance. [3] The dump body was analysed using finite element analysis under static loading conditions. A combined mild steel–aluminium design was found to provide improved structural performance with reduced weight and better corrosion resistance[4] This study compared steel and composite chassis using finite element analysis. Composite materials reduced vehicle weight while providing satisfactory structural strength for heavy-duty applications.[5] This work designs a battery-powered three-wheeler with a robotic arm to automate waste collection and enhance sanitation safety [6] The paper analyzed a truck load body under static loading using finite element analysis. The optimized design improved structural performance by reducing stress concentration and ensuring safe load-carrying capacity.[7] The study investigated lightweight electric vehicle chassis by comparing different structural materials through finite element analysis under battery, component, passenger, and overload conditions. The analysis identified a lightweight alloy as a suitable alternative by providing lower stress levels with acceptable structural performance for electric vehicle applications.[8] This study optimized a tipper dump body using finite element analysis by comparing different design models. The optimized design reduced weight and material usage while maintaining safe structural performance and improving payload efficiency.[9] This research utilizes CAD modeling and ANSYS finite element analysis to optimize E-rickshaw chassis frames by evaluating structural integrity and safety across various material compositions[10]

Although previous studies have investigated lightweight chassis design, material selection, and dump body optimization, limited work has focused on the combined structural evaluation of both the chassis and cargo box of electric garbage collection vehicles. In addition, the structural influence of corrosion-induced thickness reduction in the cargo box has received limited attention. Therefore, the present study evaluates the structural behaviour of both components using finite element analysis and investigates suitable alternative materials together with redesign strategies to achieve weight reduction while maintaining structural safety.

Methodology

The present study deals with the structural evaluation of the chassis and cargo box of an electric garbage collection vehicle using finite element analysis under static loading conditions. Initially, the chassis and cargo box models were prepared in Solid Edge according to vehicle design requirements and operating conditions. The developed models were then imported into ANSYS Workbench for structural analysis.

Mild Steel, Aluminium Alloy 6061-T6, AISI 4130 steel, ASTM A710 steel, and Stainless Steel 304L were selected for comparative analysis based on their structural and corrosion-resistant properties. Suitable material properties, loading conditions, and support constraints were assigned to represent practical working conditions of the vehicle.

Static structural analysis was carried out to study the equivalent stress and total deformation developed in the chassis and cargo box structures. In the chassis, selected non-critical regions were considered for thickness modification to reduce structural weight, while the cargo box wall sections were assessed considering corrosion-related thickness reduction. The obtained results were compared to identify the structurally stable and efficient configuration suitable for electric garbage collection vehicle applications.

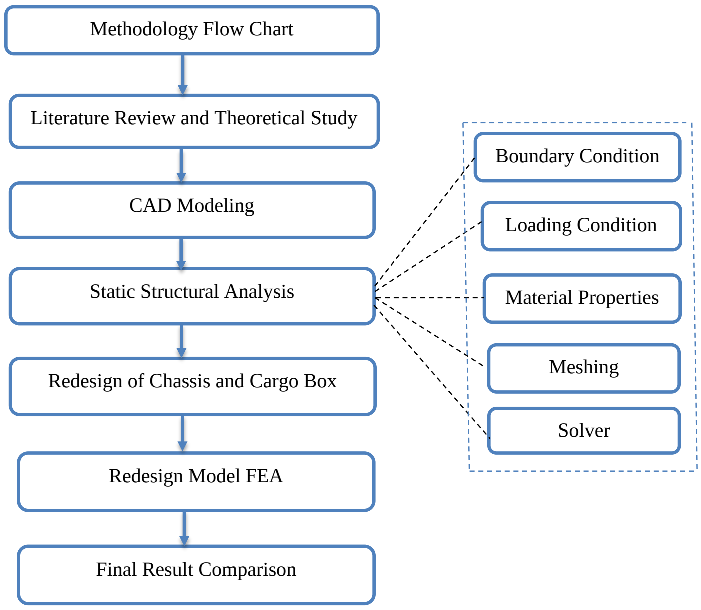

Figure 1. Methodology for Structural Analysis and Optimization

Material Selection

The materials for the chassis and cargo box assembly were selected considering structural strength, stiffness, weight reduction, and corrosion resistance under municipal solid waste operating conditions. The current structural material used is mild steel, and the following are the alternate materials selected for comparison of structural properties: aluminium alloy 6061-T6, AISI 4130 steel, ASTM A710 steel, and stainless steel 304L because these materials provide superior mechanical prop-erties and are suitable for the use in vehicle structural applications.

For the evaluation of alternative materials to reduce the weight of the chassis structure while providing sufficient load-carrying capacity and stiffness were conducted using the alternate materials. In the cargo box structure, the selected materials were analysed to study the structural effect of corrosion-induced thickness reduction occurring during long-term waste handling operation. Material properties such as Young's modulus, density, Poisson's ratio, and yield strength were assiglned in ANSYS Workbench to evaluate the equivalent stress, total deformation, and overall structural response of the chassis and cargo box assembly under static loading conditions.

Table 1. Material Properties

Property	Mild Steel (Existing)	AISI 4130 Steel	ASTM A710 Steel	304L Stainless Steel	Aluminium 6061-T6
Density (kg/m³)	7800	7790	7850	7900	2770
Young's Modulus (GPa)	207	207	205	200	71
Poisson's Ratio	0.33	0.29	0.29	0.28	0.33
Tensile Yield Strength (MPa)	550	460	585	190	275
Ultimate Tensile Strength (MPa)	620	560	620	564	300

Modeling

The three-dimensional models of the electric garbage collection vehicle chassis and cargo box were developed using Solid Edge, as shown in Fig. 2 and Fig. 3. The chassis consists of longitudinal frame members, cross members, curved support sections, and mounting brackets, while the cargo box includes the base plate, side panels, front panel, and stiffeners. The geometrical dimensions were developed according to the design requirements and operating conditions of the vehicle

The chassis was designed to provide adequate strength, stiffness, and load-carrying capability under battery, motor, and payload loads. The cargo box was modelled to safely withstand uniformly distributed municipal solid waste while maintaining structural rigidity during operation. Proper assembly alignment and structural connections were considered to represent the actual vehicle configuration.

The developed CAD models were imported into the finite element analysis environment for static structural analysis. Appropriate material properties, boundary conditions, and service loads were applied to evaluate equivalent stress and total deformation. Chassis thickness optimization was performed to reduce structural weight, whereas selected cargo box wall panels were analysed with reduced thickness to investigate the effect of corrosion-induced material loss on structural performance.

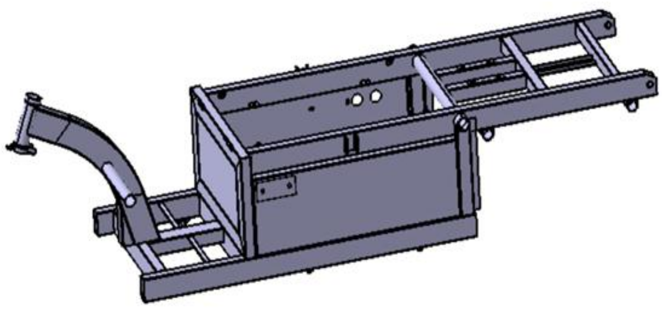

Figure 2. chassis

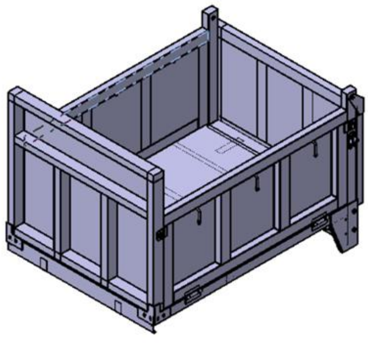

Figure 3. Cargo Box

Finite Element Analysis (FEA) Methodology

The structural behaviour of the electric garbage collection vehicle chassis and cargo box was evaluated using ANSYS Workbench. Three-dimensional CAD models developed in Solid Edge were imported into ANSYS for static structural analysis, as shown in Fig. 4 and Fig. 5. The material properties used are listed in Table 1.

Static loads representing the battery, motor, cargo box, chassis self-weight, and municipal solid waste were applied to simulate actual operating conditions. Corrosion-induced material loss was considered by reducing the thickness of selected cargo box wall regions. The models were meshed with appropriate element sizing, and equivalent (von Mises) stress and total deformation were evaluated to assess structural performance. Similar FEA procedures have been reported for truck body structural assessment and design optimization.

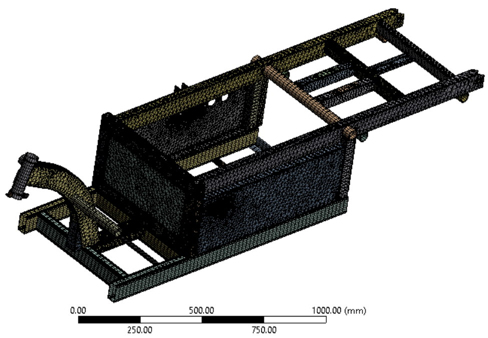

Figure 4. Meshing of Chassis

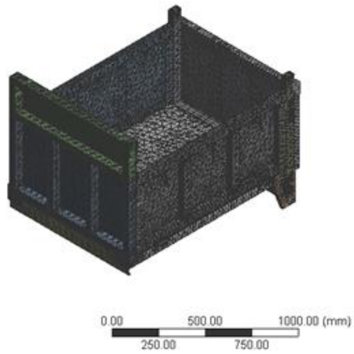

Figure 5. Meshing of Cargo Box

Boundary Conditions and Loading for chassis

Static structural analysis of the electric garbage collection vehicle chassis was performed in ANSYS Workbench to evaluate the structural response under the applied loading conditions, as shown in Fig. 6. Mild Steel was considered as the existing chassis material, while Aluminium Alloy 6061-T6, AISI 4130 steel, ASTM A710 steel, and Stainless Steel 304L were considered as alternative materials for comparative structural analysis.

The chassis structure was subjected to static loads corresponding to the battery, motor, and cargo box assembly. A battery load of 1588.67 N was applied at the battery mounting region because the battery pack transfers its entire weight to the chassis through its mounting brackets during vehicle operation. A motor load of 73.55 N was applied at the motor mounting location to represent the actual load transmitted from the electric drive unit to the chassis. A cargo box load of 887.55 N was applied at the cargo box mounting points since these locations transfer the combined weight of the cargo box and the collected waste to the chassis. Fixed support conditions were assigned at the front wheel mounting brackets and rear axle clamp regions to represent the actual support provided by the suspension and axle assembly. Standard Earth gravity of 9806.6 mm/s² acting in the positive X-direction was applied to account for the self-weight of the chassis and all mounted components under static operating conditions

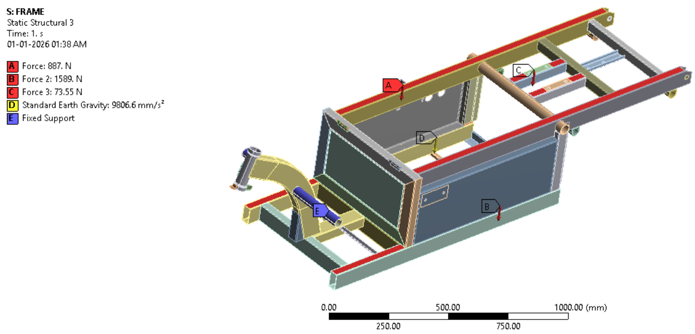

Figure 6. Boundary Condition of Chassis

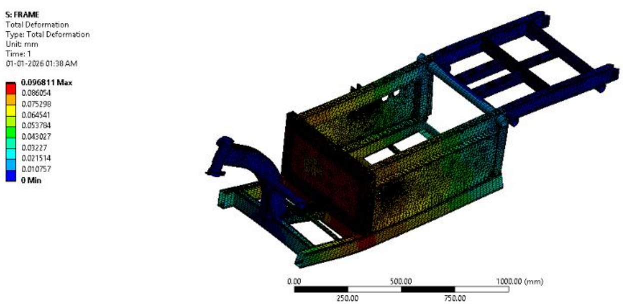

Figure 7. Deformation of Chassis

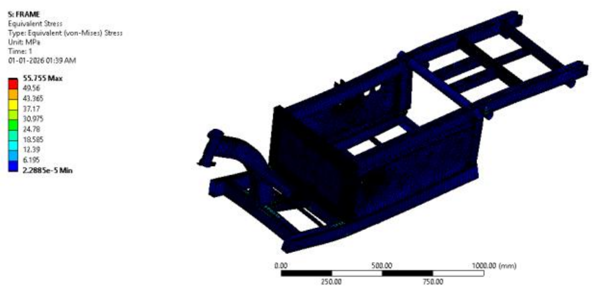

Figure 8. Equivalent Stress of Chassis

The static structural analysis of the electric vehicle chassis shows a maximum total deformation of 0.0968 mm, observed near the upper central region of the frame, indicating adequate stiffness and controlled displacement under the applied loading conditions. The corresponding equivalent (von-Mises) stress reaches a maximum value of 55.755 MPa, mainly concentrated near the Front mounting and middle part of chassis and load transfer regions. Both the deformation and stress values are well within acceptable limits for structural safety, confirming that the chassis can safely withstand the applied loads due to the battery, motor, cargo box, and self-weight without any risk of yielding or structural failure

Boundary Conditions and Loading for cargo box:

Static structural analysis of the cargo box was performed in ANSYS Workbench under linear elastic loading conditions, as shown in Fig. 9. Mild Steel was considered as the existing material, while Aluminium Alloy 6061-T6, AISI 4130 steel, ASTM A710 steel, and Stainless Steel 304L were considered as alternative materials for comparative structural analysis.

The cargo box structure was subjected to a total waste load of 315 kg (3090 N). A uniformly distributed pressure of 0.002724 MPa was applied on the inner bottom plate because the majority of the municipal solid waste load is directly supported by the base of the cargo box during normal operation. To represent the lateral pressure exerted by the waste, pressures of 0.0005443 MPa on the left wall, 0.0005443 MPa on the right wall, 0.0004576 MPa on the front wall, and 0.0006321 MPa on the rear wall were applied to their respective inner surfaces. These pressures simulate the side forces developed due to the interaction of the waste with the cargo box walls during loading, transportation, braking, and unloading operations. Fixed support conditions were assigned at the cargo box mounting locations to represent the actual bolted connections through which the cargo box is attached to the chassis. Standard Earth gravity of 9806.6 mm/s² acting in the positive X-direction was applied to account for the self-weight of the cargo box during static loading conditions.

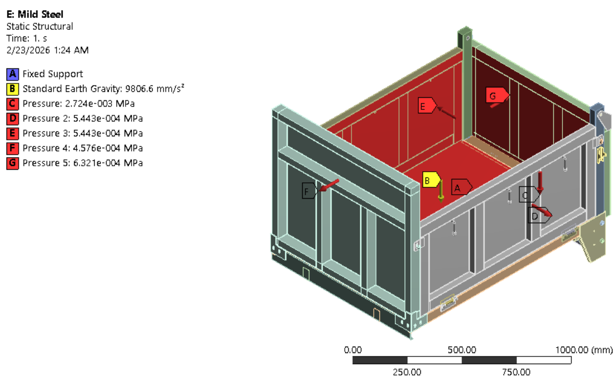

Figure 9. Boundary Condition of Cargo Box

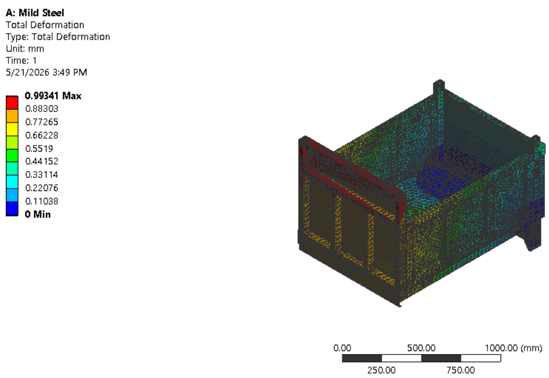

Figure 10. Deformation of Cargo Box

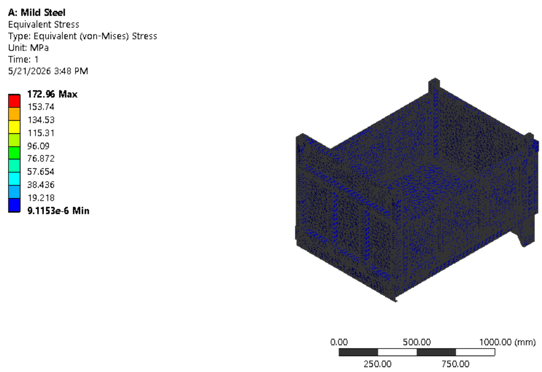

Figure 11. Equivalent Stress of Cargo Box

The static structural analysis of the cargo box under the applied static load is presented in Figures 10 and 11. The finite element results show a maximum total deformation of 0.99341mm, observed at the upper front region of the cargo box.

The corresponding maximum equivalent (von Mises) stress obtained from the stress contour is 172.96MPa, developed in regions actively participating in load transmission. The computed stress value is below the yield strength of Mild Steel, indicating that the structure remains within the elastic range under the given loading condition.

Redesign of Chassis and Cargo Box

The chassis and cargo box of the electric garbage collection vehicle were modelled using Solid Edge software. The chassis was developed as a ladder-type frame structure to support major vehicle components, including the cargo box, battery pack, motor assembly, and powertrain system. Longitudinal members connected through cross-members were provided to ensure adequate load distribution and structural stability during operation.

To achieve a lightweight design, modifications were introduced in selected non-critical regions of the chassis. The thickness of selected structural members was reduced by 0.5 mm, while the sectional dimensions of selected cross-members and secondary support members were slightly refined in low-stress areas. In such a manner, all convertible ties and non-load bearing supports were removed or detached to reduce excessive loads on the structural elements. All additions have been done without any modifications to or alterations of the original main load-bearing members of any kind. In addition to not damaging the structural integrity or rigidity of the chassis.

The cargo box was redesigned to assess the effect of corrosion-induced material loss on structural performance. A thickness reduction of 0.2 mm was considered in selected wall sections of the cargo box to represent material loss that may occur during long-term exposure to municipal solid waste and moisture-rich operating conditions. The base plate, stiffener-supported regions, and other critical load-bearing sections were retained without modification to preserve the structural integrity of the cargo box.

The redesigned chassis and cargo box were subsequently evaluated through static structural analysis. The structural behaviour of the modified designs was assessed in terms of equivalent stress, total deformation, and overall stability under the specified loading conditions. The proposed modifications resulted in reduced structural weight while maintaining adequate load-carrying capability and structural safety for electric garbage collection vehicle applications.

Result and Discussion

The static structural analysis results for the existing and redesigned chassis and cargo box are presented in Tables 2 and 3, while the corresponding graphical comparisons are shown in Figures 12–17. The graphs provide a clear comparison of equivalent stress, total deformation, and structural weight for the selected materials.

The redesign of the chassis achieved a reduction in weight while still providing acceptable values for stress and deformation at an acceptable level, as illustrated in the Figures 12, 13, 16 . The lightest weight and maximum amount of deformation occurred for Alloy 6061-T6 (Aluminum Alloy), while the best weight, strength and stiffness balance was achieved with ASTM A710 (Steel).

In the case of the cargo box, only slight increases occurred in the equivalent stresses and total deformation, as illustrated in the Figures 14, 15, 17, as a result of the localized reduction in thickness only. The results indicate that the redesigned structure maintained structural safety while reducing weight, with ASTM A710 steel demonstrating the most favourable overall performance.

Table 2. Comparison of Existing and Optimized Chassis Analysis Results

Materials	Existing Deformation (mm)	Existing Stress (MPa)	Existing Weight (kg)	Optimized Deformation (mm)	Optimized Stress (MPa)	Optimized Weight (kg)
Mild Steel	0.0968	55.755	53.83	0.14747	75.212	46.121
AISI 4130 Steel	0.09337	55.742	53.773	0.14209	76.114	45.768
ASTM A710 Steel	0.094428	55.811	53.70	0.14366	76.186	45.850
304L Steel	0.096886	55.925	54.173	0.14732	76.491	46.415
Aluminium 6061-T6	0.23671	49.835	18.995	0.37139	69.06	16.275

Table 3. Comparative static structural analysis results of the existing and redesigned cargo box

Material	Existing Deformation (mm)	Existing Stress (MPa)	Existing Weight (kg)	Redesigned Deformation (mm)	Redesigned Stress (MPa)	Redesigned Weight (kg)
Mild Steel	0.99341	172.96	100.84	1.0671	177.25	97.442
AISI 4130 Steel	1.0354	172.82	101.49	1.0337	176.8	96.678
ASTM A710 Steel	0.99064	172.45	100.84	1.0459	177.09	97.442
304L Stainless Steel	0.99568	172.34	100.07	1.0746	177.29	98.043
Aluminium 6061-T6	2.3579	147.65	35.584	2.4856	153.14	34.377

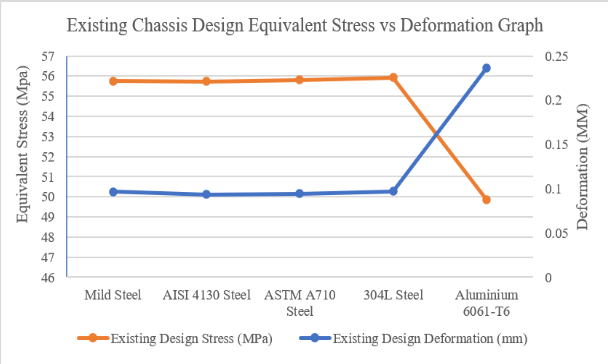

Figure 12. Existing Chassis Design Analysis Graph

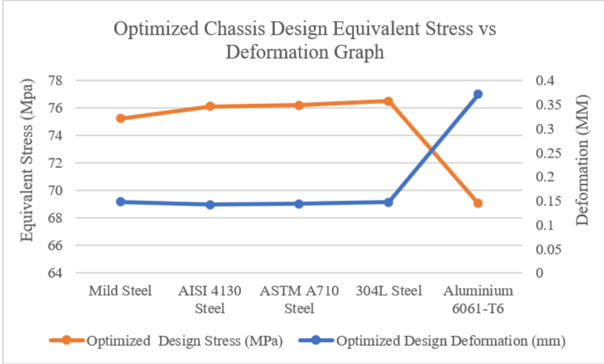

Figure 13. Optimized Chassis Design Analysis Graph

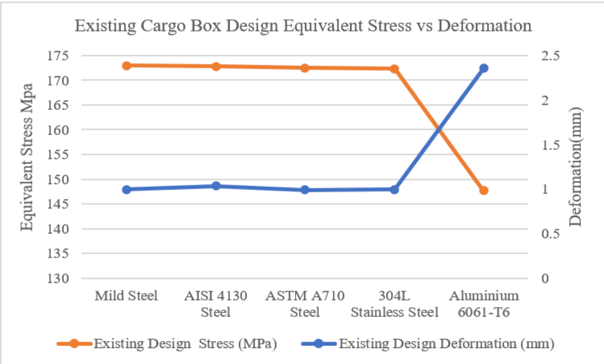

Figure 14. Existing Cargo Box Analysis Graph

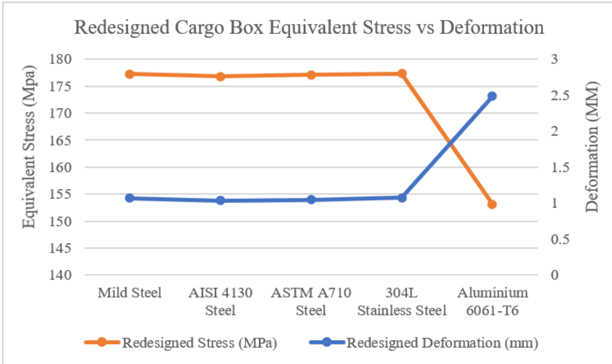

Figure 15. Redesigned Cargo Box Analysis Graph

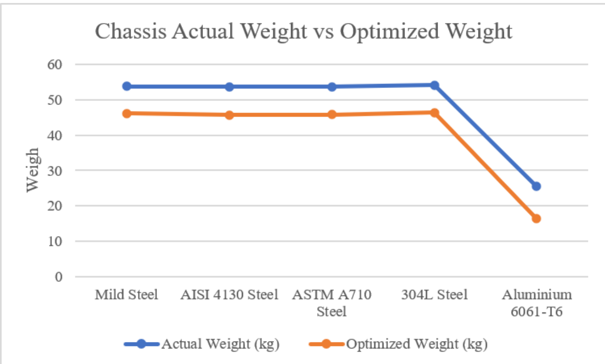

Figure 16. Existing vs Redesigned Chassis Design Weights Graph

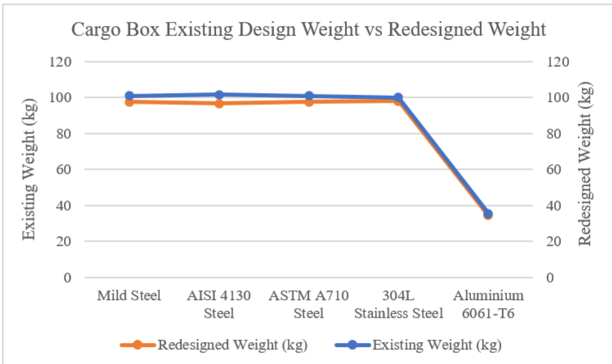

Figure 17. Existing vs Redesigned Cargo Box Weights Graph

Conclusion

The present work focused on the structural behaviour of an electric garbage collection vehicle chassis and cargo box using finite element analysis. Mild Steel is classified as the Existing Material, while Aluminium Alloy 6061-T6, AISI 4130 Steel, ASTM A710 Steel, and Stainless Steel 304L were examined as potential alternative Materials for use in structural comparisons.

Based on an analysis of the redesigned chassis, the proposed design modifications did not result in any critical structural issues concerning the load conditions applied. During the evaluation of the structural integrity of the cargo box, the potential effects of corrosion from handling corrosive waste in the environment were accounted for. The obtained response indicated that the structure remained capable of carrying the prescribed load without significant changes in its overall behaviour.

Differences in structural response and weight were observed among the selected materials. Based on the numerical results, ASTM A710 Steel exhibited a favourable balance between strength and weight when compared with the existing Mild Steel configuration. The study suggests that the proposed chassis and cargo box design is suitable for electric garbage collection vehicle applications where structural reliability, durability, and weight reduction are important considerations.

References

[1] P. V Vijaykumar and R. I. Patel, "Structural Analysis of Automotive Chassis Frame and Design Modification for Weight Reduction." vol. 1, no. 3, May 2012, ISSN: 2278-0181.

[2] S. Vinjavarapu, U. Koteswararao, and V. L. Narayana, "Design Optimization of Tipper Truck Body." vol. 4, no. 9, pp. 11–20, Nov. 2012, ISSN: 2278-067X.

[3] A. Sharma, M. Pramod Kumar, A. Jabbar, and M. M. Khan, "Structural Analysis of a Heavy Vehicle Chassis Made of Different Alloys by Different Cross Sections.". Available: www.ijert.org

[4] R. K, S. R. S, and S. R. B, "Design and Analysis of Dump Body on Three Wheeled Auto Vehicle," *International Journal on Cybernetics & Informatics*, vol. 4, no. 2, pp. 65–73, Apr. 2015, doi: 10.5121/ijci.2015.4206.

[5] A. Siraj, N. R. Babu, and K. S. Reddy, "Static analysis of dump truck chassis frame made of composite materials," *International Journal of Engineering, Science and Technology*, vol. 11, no. 2, pp. 21–32, Apr. 2019, doi: 10.4314/ijest.v11i2.2.

[6] S. G. Ghugal, G. Bedre, P. Karande, M. Karemore, and T. Ghyar, "Design of Automatic Garbage Collecting Vehicle," *International Research Journal of Engineering and Technology*, p. 2393, 2008, Available: www.irjet.net

[7] H. K. Kulkarni and M. B. Mandale, "Advances in Automobile Engineering Design and Analysis of Truck Load Body for Low Commercial Vehicle Platform," 2022, doi: 10.35248/2167-7670.1000187.

[8] V. Omidiji, A. Owolabi, M. Oluwasegun, and E. Fabunmi, "Structural Analysis of a Lightweight Electric Vehicle Chassis," *MATTER: International Journal of Science and Technology*, vol. 10, pp. 139–154, 2024, doi: 10.20319/mijst.2024.10.139154.

[9] N. Bhavani Sankar, "Optimization of Material Usage in The Fabrication of Dump Body." vol. 4, no. 5, pp. 3596–3604, Aug.–Sep. 2016, ISSN: 2320-5547.

[10] "Design and Analysis of Electric vehicle chassis for better performance," *International Research Journal of Modernization in Engineering Technology and Science*, Sep. 2024, doi: 10.56726/irjmets61623.