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Weight reduction analysis of a four-door passenger car using computer-aided modelling and experimental investigation

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ABSTRACT

The door of a passenger car is one of the key components used for the safety of passengers from side collisions. Mostly car doors are made of Steel that increase the overall weight of the vehicle since steel is the primary metal used for the construction of door. The main objective of this research is to replace Steel material of a car door with low-cost automotive materials such as aluminium alloy, magnesium alloy, and carbon fibre material to perform weight reduction analysis without compromising the strength and safety. A comprehensive theoretical study of the existing car door has been performed with 3D Computer-Aided Design (CAD) models through commercially available software SolidWorks. Results of this research work revealed that by selecting the appropriate engineering materials of the doors for a commercially available passenger car, the overall weight reduced to 45% when used aluminium material and 64% when used magnesium and carbon-fibre materials compared to the total weight of four doors made of typical steel material. Furthermore, reduction in fuel consumption and CO2 emission was also obtained by reducing the overall weight of the passenger car doors. Lastly, the performance was measured through power-to-weight ratio (PWR) analysis for steel and aluminium which revealed that the latter material was more economical and lighter in weight than the former material.

1. Nomenclature

σt	Tensile strength
ρ	Density
Al	Aluminium
Mg	Magnesium
CAD	Computer-Aided Design
CO2	Carbon dioxide
CFRP	Carbon fibre reinforced polymer
E	Young’s modulus
OEM	Original Equipment Manufacturer
g	Gram
kg	Kilogram
km	Kilometre
L	Litre

2. Introduction

A vehicle door is a typical type of door sometimes hinged or attached by other mechanisms such as tracks and is used to enter and exit a vehicle, when it is closed it provides safety and when it is open it provides access to the vehicle. A vehicle door can operate electronically or manually. In car and door-closure design, mass reduction provides numerous benefits in addition to reduced cost. Such benefits include reduced fatigue load and improvements in manufacturing assembly. [1] As a result, there continues to be a critical push to reduce mass in vehicle body and door designs. Reducing weight by 100 kg leads to a fuel savings of 0.3 to 0.5 L/100 km and 8.5g to 14g CO_2/km with gasoline engines as shown in the Fig. 1.[2]

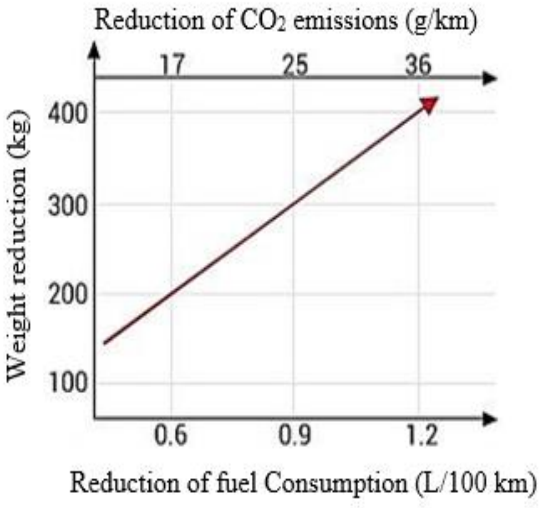


Fig. 1. Effect Weight Reduction on CO_2 Emission and Fuel Consumption [2]

Consider an adjustment of the gear shifting without a change in elasticity and acceleration values due to the lower weight [1]. A lightweight body of a vehicle can be achieved through any combination of five different approaches to lightweight design as shown in Fig. 2, categorized into use of lightweight materials, optimizing existing designs, re-sizing parts and systems [3], revising manufacturing operations, removing content/features (Fig. 2). In a study to reduce overall weight of the vehicle using natural fibre metal laminate, the application of TRIZ (theory of inventive problem solving) method used to solve several problems that may occur during the utilisation of natural fibre metal laminate. Their method also helped to reduce engine gasses emissions using less fuel and reduced the effects associated with global warming. [4].

This research work primarily focused on the reduction of weight for a passenger car by using lightweight materials. For this purpose, focus is on aluminium and magnesium alloys. In addition to these materials, present research has also used composite i.e., carbon fibre which is having specific strength than these materials.[5].

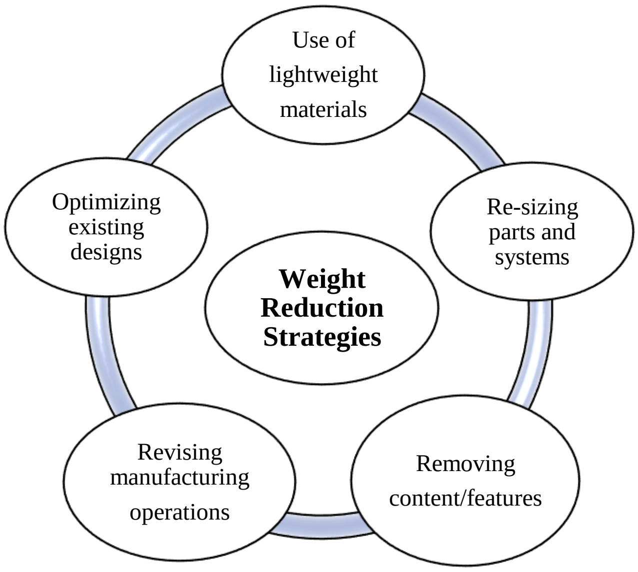


Fig. 2. Different Weight Reduction Strategies

This research work primarily focused on the reduction of weight for a passenger car by using lightweight materials. For this purpose, focus is on aluminium and magnesium alloys. In addition to these materials, present research has also used composite i.e., carbon fibre which is having specific strength than these materials.[5]. However, the competition between materials like aluminium magnesium and carbon fibre plays an important role to reduce vehicle mass component by component such as engine body, panels, doors etc. The weight of a vehicle is distributed into different categories or parts which include body (23-28%), power train (24-28%), chassis (22-27%), interior (10-15%), closures (7-8%) and other miscellaneous components and parts (7-8%). [2] By comprehensive study automakers realized the impact of replacing Steel auto bodies with aluminium, magnesium and carbon fibre (composites) saves up to 21% to 38% of weight with additional manufacturing cost.[6] Another important fact is that by replacing Steel parts with aluminium and magnesium-based parts 12% to 16% reduction in CO_2 emissions can be achieved [2]. In order to reduce the overall weight of the vehicle using natural fibre metal laminate, the application of TRIZ (theory of inventive problem solving) method used to solve several problems that may occur during the utilisation of natural fibre metal laminate. Their method also helped to reduce engine gasses emissions using less fuel and reduced the effects associated with global warming. [4]. The environmental impact of material selection was analysed in in components of a car body through side door intrusion beam. They performed a series of tests and quantified the impact on environment by life-cycle assessment tool. The obtained results highlighted that the glass-fibre reinforced thermoset (3 kgCO2eq) and carbon-fibre reinforced thermoplastic (4 kgCO2eq) appeared to have less environmental impact among the analysed materials. [7]. The frequency map of the door used to extract and compare a reference map to identify complicated parts in a car such as door and hinges. In their analysis, a car door geometry was modelled in CATIA and meshed in hyper mesh software. Then, a modal analysis between 0-50 Hz was done by hyper mesh. [8]. The characterization of a Carbon Fibre Reinforced Plastic (CFRP) was presented and a couple of damping materials, particularly suited to the manufacturing process of composites. Young's modulus and loss factor of each material were defined by means of the Oberst beam test method, where a specific curve fitting technique replaces the half-power bandwidth procedure to ameliorate the estimates of the parameters. They inferred that the damping material could effectively ameliorate the noise and vibration response of the structure. [9]. The analysis and design of side door intrusion beam in automotive safety was studied. Their research focused on the comparative study of 3 cross-sectional profiles, 3 gauges and 3 materials for side door intrusion beam, whereas Taguchi method was used to optimize design parameter by using FEA model on three-point bending simulations. [10]. It was observed that light weighting has become a main issue for energy efficiency in automotive industry. Fuel efficiency and emission of gases of this industry are two important issues. R&D played an important role in reducing weight since it is the best way achieving low consumption of weight. Compared to commonly used metals CFRP is a composite material and has outstanding specific stiffness, fatigue properties and specific strength which is why highly it introduced bet potentials and recommended for light weight applications in automotive industry. [11]. The challenges in automotive industry were studied and found the most difficult task reducing the weight of vehicles minimizing energy consumption. The employment of composite materials would help reducing weight of electrical vehicles. This way it will help reducing harmful emissions and fuel consumptions. CFRP has been with significance attraction in light weigh applications in automotive industry. [12]. Modern transportation and circular economy solutions lightweight materials has enormous demand in automotive industry. It helps the environmental sustainability and corporate social responsibility concepts. R&D in global activities came into understanding of introducing metallic alloys sector that cover "lightweight steel", magnesium alloys and conventional aluminum which helps in transition from internal combustion engines to electric vehicles together with well-established technologies of component manufacturing. [13]. Heavy weight materials are now burden on leading automobile industries due to its adverse effects on economy and environment. Though the heavy weight materials have significantly high strength, but with high production cost divert the producers to advanced materials like high strength steel, magnesium, aluminum and CRFP. Observed 1st impact "economic advantage" understanding fuel consumption by reducing weight for all components employing overall vehicle weight reduction and 2nd impact "environmental advantage" and reduction in carbon emission. [14]. It was observed and proposed the weight reduction of automotive components from high weight steel to low weight aluminum, magnesium and CFRP. Estimated electric vehicles will be 35% of the current by 2025 and will be driven by battery. Not only low density but because of its heat transfer capabilities Aluminum becomes more competitive for batteries lying sheets and skateboards chassis in the automotive electrical vehicles. [15]. Observed and tested bio-based PA11-wood fibres composites as substitutes to PP-GF materials, which was based on interior car door handle. The authors proposed using a wood fibre reinforced polyamide 11 composite as replacement. Moreover, their research discussed the mechanical properties of such composites, obtaining values similar to the currently used materials. A car's door typically hinged to the body and used to enter or exit the car. Car doors can open manually or powered electronically. The exterior side of the door has a good finish and typically composes of Steel or other material like the cars' exterior body. While the interior side or panel of the door has decorative components, and it supports those components. The main components of the car door are the outer panel, inner panel, impact beam, doorframe, door handle, door switch, glass window, and power door locks. To have real-time industrial exposure, visited a renowned automobile manufacturer and gathered the precious knowledge of car door manufacturing and the materials used in its manufacturing as shown in Fig. 3.

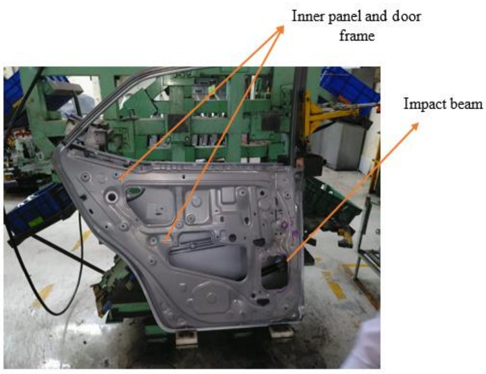


Fig. 3. Main Parts of A Car Door

Lightweight materials became important for automakers and, aluminium, magnesium and other materials used along with Steel. The weight of Steel used in manufacturing was reducing day by day, but it could not be completely wiped-out. [2] The impact test of door must have the ability to absorb as much energy without breaking. Steel is one of the most important materials used in car door but in fact, Steel increases overall weight of the car. The properties such as specific strength (σ_t/ρ) and specific stiffness (E/ρ) are attractive and plays an important role for the construction of lightweight and fuel economic structure. [17] Weight of the vehicle is directly related to fuel efficiency as 75% overall weight of the vehicle contributes to fuel consumption.[18][19]. By decreasing 10% weight of the vehicle could increase fuel efficiency up to 6 to 8 %. [15] As mentioned previously, reducing car weight to 100 kg gives fuel savings of 0.3 L to 0.5 L/100 km and 8.5 g to 14 g of CO_2/km. Audi-R8 is the living example, the key factor behind the design is lightweight body [21] shell with multi material body spaceframe and it weighs only 200 kg. [22] From the literature review, it is clear that the past researchers have not performed weight reduction analysis using different materials such as aluminium, magnesium and carbon-fibre. Furthermore, in the presented research work, a comprehensive theoretical study of the existing car door has been performed through 3D Computer-Aided Design models through a commercially available software SolidWorks in conjunction with experimental measurements for calculations of CO_2 emission, stiffness, and performance in terms of power-to-weight ratio (PWR), which highlight the novelty of presented research.

2.1 Selection of Materials and Their Properties

Automobiles are becoming heavier, and the main purpose is to satisfy safety such as collision safety and pedestrian protection, drivability, comfort-ness and larger interior space. However, automobiles have to meet the regulations against exhaust emissions, such as CO_2 and NOx emissions, to protect the environment and global. Thus, reducing fuel consumption is now imperative and a must do thing for all the automobile manufacturers specially for automobile manufacturer. [23] If one hundred kilograms of weight has reduced than it improves fuel consumption by approximately 1 km/L. Reduction in automobile's weight has been achieved traditionally by reducing thickness of Steel-sheet body panels by increasing the strength of the Steels, however, this approach is limited because of the resultant reduction in the stiffness of the panel. For this reason, lighter materials being studied extensively used and replacing the Steel. Especially, aluminium alloys magnesium alloys and carbon fibre have started to be used for various automotive parts because of their low density and high tensile strength. [19] Now the use of aluminium and magnesium alloy and carbon fibre is not limited to engine blocks, rims, and hoods but extends to trunk lids, outer panels such as doors and protection covers including heat insulators. Cole and Sherman [24] gave the evidence that the use of lightweight metals (such as aluminium, magnesium and carbon fibre) into automobile parts directly saves the overall weight and different gas emissions. Table 1 presented the mechanical properties of selected materials in this research work.

Table 1

Mechanical properties of considered materials [20], [25]

Material	Tensile strength (MPa)	Density (kg/m^3)	Specific strength (kN·m/ kg)	Elastic Modulus (GPa)	Poisson's Ratio
Carbon Steel	365	7858	46.4	210	0.3
Aluminium alloy (5022)	310	2700	115	70	0.33
Magnesium alloy (AT72)	275	1750	158	45	0.3
Carbon fibre	4300	1750	2457	181	0.31

3. Research Methodology

There are several approaches [1], [2], [22] through which lightweight model can be achieved such as resizing the parts, lightweight materials, optimizing the existing design, revising manufacturing processes and removing content and features. This research methodology is focused more towards material's change i.e., lightweight materials approach. For reducing weight by using different materials, at first, the model of considered vehicle 2015 Toyota Corolla 1.6L developed through CAD. For the development of CAD model, blueprints of this vehicle are required and by using blueprints, surface modelling performed. Furthermore, different materials such as carbon steel, aluminium alloy, magnesium alloy, and carbon fibre used in the developed CAD model. Materials including aluminium, magnesium and carbon fibre assigned on selected vehicle front left door and after that applied on all four doors of modelled vehicle. It has observed that by reducing the weight, not only the fuel efficiency increases but also CO_2 emission also reduces. Therefore, weight reduction is directly proportional to the reduction in CO_2 emissions. Hence, if all the conditions are satisfied as shown in the flowchart (Fig. 4) it concludes that desire goal achieved.

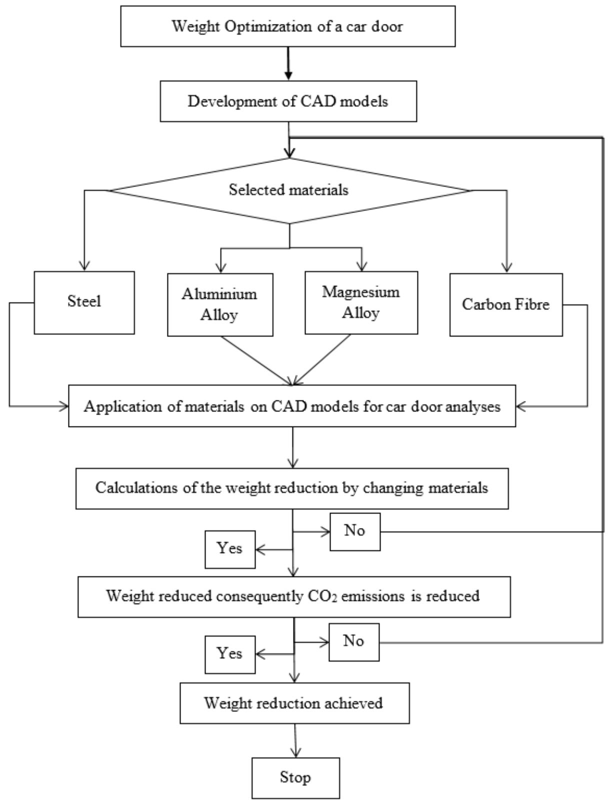


Fig. 4. Research Methodology Used in Weight Reduction For Passenger Vehicle

4. Computer-Aided Modelling

CAD technology used in the detailed drawings and engineering of physical components of 3D models or 2D drawings, it can also be used through engineering processes such as conceptual design and layout of products through dynamic and strength analysis of assemblies. Modelling on CAD software has become a need for every industry. However, different software has different interface and works a little differently, but the basic logic and concepts are same. To make the CAD of a vehicle body, blueprints of that vehicle are required. Then these blueprints used for the surface modelling of the vehicle body. The blueprint of selected vehicle model is adjusted [31] and then they are used to develop 3D model of considered vehicle as shown in the Fig. 5. This CAD of the vehicle body then used to extract individual parts such as the door and, further analysis on the door can perform through software.

The car taken for this research work is vehicle 2015 Toyota Corolla model because of its commercially availability and a hatchback with engine of 1600cc. [32] The blueprints of this car are available and directly considered from the source. [31] These views then edited and a sketch obtained with the proper dimensions and curves. These blueprints used for the surface modelling of the vehicle body as mentioned in Fig. 6.

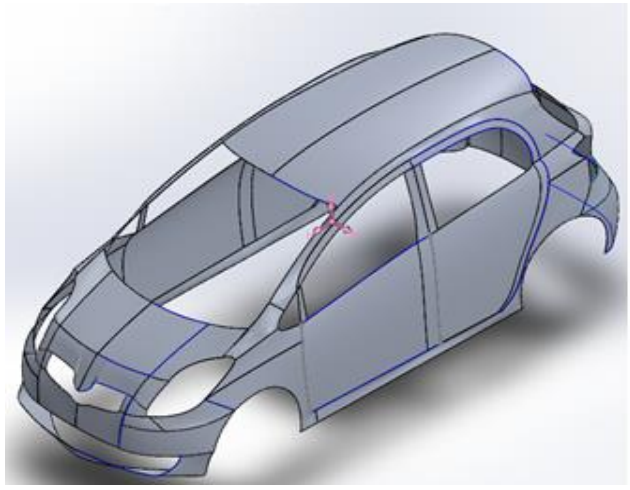


Fig. 5. CAD Model of The Considered Vehicle

The car taken for this research work is vehicle 2015 Toyota Corolla model because of its commercially availability and a hatchback with engine of 1600cc. [32] The blueprints of this car are available and directly considered from the source. [31] These views then edited and a sketch obtained with the proper dimensions and curves. These blueprints used for the surface modelling of the vehicle body as mentioned in Fig. 6.

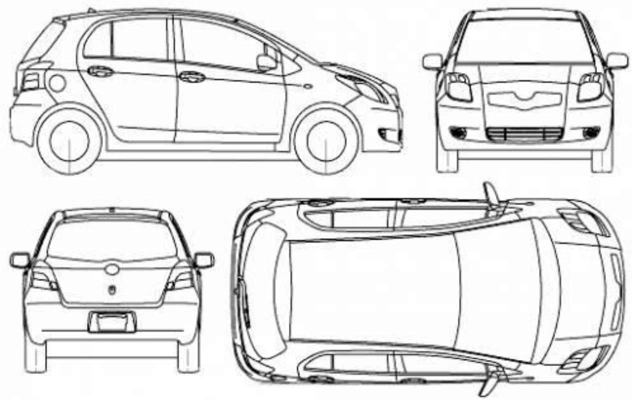


Fig. 6. Blueprint Of the Considered Vehicle Model

The surface modelling is a tool used in developing complex surfaces by using 3D curves. In SolidWorks the module and then sketch tracer used in which the views are imported and then the views sketched by using 3D curves (Fig. 7).

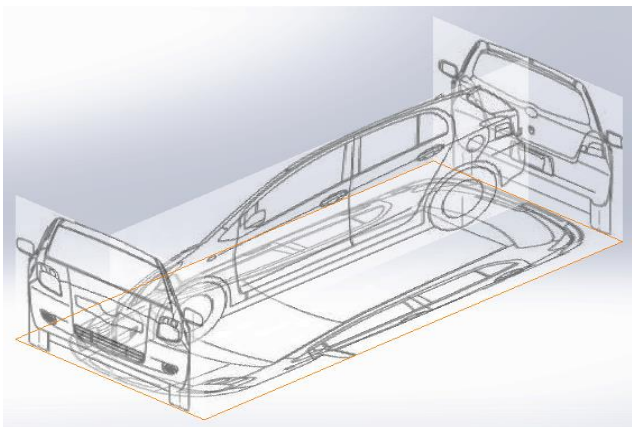


Fig. 7. Imported Blueprints of Considered Vehicle Model

These curves modified and fitted to all dimensions. The wireframe of the car then obtained. Tools that are used for modelling from blueprints are spline, 3D sketch, centre line. This developed CAD model is applicable for various research purposes as in this paper, different materials used through the developed CAD model.

5. Experimental Measurements

For the validation of the above CAD models, a practical demonstration was carried out on a real 2015 Toyota Corolla 1.6L car door, as shown in Fig.s 8 (a) and (b). Fig. 8 (a) presents the magnified view of dial indicator for the measured weight of a single car door made of steel material. For the sake of ease, only one door was considered for experimentation, the results of which were matched with the CAD modelling and then associated with the remaining three doors of the car. This fact was further proven in the experimental setup because all four doors of the car portray approximately the same dimension and weight. Thus, a typical car door made of steel material was weighed using a spring balance weighing machine that was capable of handling weight of up to 100 kg. From Fig. 8 (a) below, it can be seen that the weight of a single car door of steel material turned out to be 20 kg.

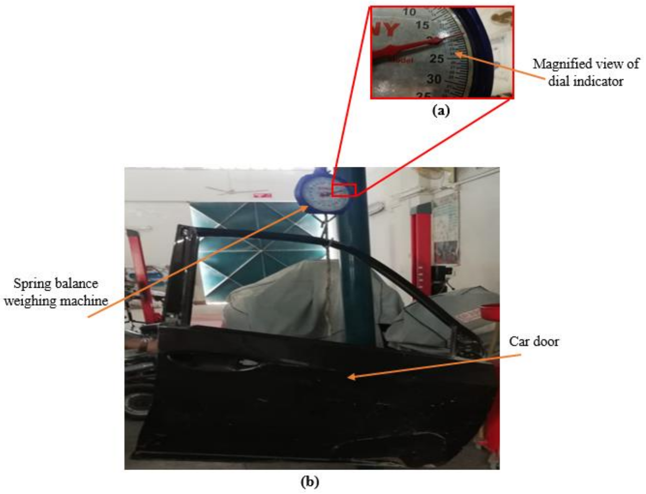


Fig. 8 (a) Weight of A Single Car Door Made of Steel Material and (b) Typical Car Door Of 2015 Toyota Corolla

To further analyse the door through CAD modelling, the thickness was calculated using Vernier calliper. This value was helpful in further calculation by changing the material from steel to Aluminium. Fig. 9 below shows the thickness, which came out to be t = 1.4 mm from the side for each car door. For the sake of ease, it was assumed that the car door kept the same thickness from all of its sides. Without this assumption, calculations would have been very complex to handle.

Fig. 9. Thickness Of a Single Car Door Made Of Steel Material

6. Results and Discussion

6.1 Door Weight Reduction Analysis

6.1.1 Considering only front left door

Fig. 10 shows the front door when carbon Steel is applied on the door with a thickness of t = 1.4 mm. The mass of the door is coming out to be 8.87 kg. For carbon Steel material, thickness (t) considered as 1.4 mm. As suggested in 2016, for other remaining three materials (aluminium, magnesium, and carbon fibre) thickness has been considered as 2.2 mm. [28].

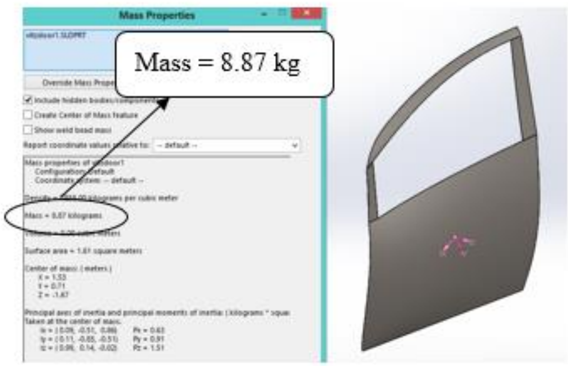
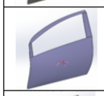


Fig. 10. Front Door, The Applied Material Is Carbon Steel (t = 1.4 mm)

CAD models are the exact representation of 3D solids, which are useful and suitable for creating physical models that helps in understanding and save time and money. In this research paper, the weight of the selected vehicle door without all accessories (mirrors, motors switch etc.,) calculated manually that comes out to be 9-10 kg (in case of Steel) and then compared by CAD model in which weight comes out to be 8.87 kg ≈ 9 kg showing that the results achieve from software are approximately accurate. Now, aluminium alloy 5022 applied as door material with thickness of t = 2.2 mm and mass reduced from 8.87 kg to 4.77 kg. Aluminium used in modern cars due to its lightweight and availability in the market. Magnesium alloy AT72 applied as door materials and more reduction in weight observed. As magnesium is lighter than Steel and is 35% lighter than aluminium [34], it can significantly reduce the door weight when it is used as door material. The weight of the door now reduced to 3.09 kg. As carbon fibre is lighter than Steel and aluminium, it can significantly reduce the door weight when used as door material. The weight of the door now reduced from 8.87 kg to 3.09 kg, which is the same mass reduction as obtained in the case of magnesium because both the materials have same density. Carbon fibre has higher strength to weight ratio as compared to magnesium, but it is more expensive than magnesium as well. As 100 kg reduction in weight will save 0.3-0.5 L/100 km gasoline and 8.5-14 gm/km CO_2. [2] Based on this fact, the weight reduction of one door considered and presented a detailed summary in Table 2. The fuel and CO_2 savings evaluated. Author assumed the fuel consumption to be 6 L/100 km according to the mileage of considered vehicle model. [32] 100 kg reduction in weight (fuel saving) = 0.5L/100 km.

Table 2

Showing mass and weight reduction's effect of one door

Door models	Material	Mass (kg)	Mass reduced (kg)	Gasoline saved per 100 km	Fuel Consumption L/100 km	CO_2 emission reduction in gm per km
	Carbon Steel	8.87	-	-	6.00	--
	Aluminium alloy 5022	4.77	4.1	0.0205	5.979	0.574
	Magnesium alloy AT72	3.09	5.78	0.0289	5.971	0.809
	Carbon fibre	3.09	5.78	0.0289	5.971	0.809

The reduction in mass in case of carbon fibre is same as that in case of magnesium. It means, by replacing Steel door with magnesium and carbon fibre, fuel savings of 0.0289 litres per 100 kilometres and 0.809 grams CO_2 emission per kilometre could be save. The design of a door is very complex. It includes inner panel, outer panel, impact beam, and reinforcements. For the sake of simplicity, deigned the outer panel and assumed it as a single unit. In actual, the thickness of inner panel is 0.7 mm for mild Steel and that of outer panel 0.7 mm as well. Therefore, 1.4 mm is the thickness given to the door model in case of mild Steel. In case of aluminium alloy 5022, 2.2 mm is the thickness given to the model to achieve approximately the same strength as that of mild Steel. In case of magnesium alloy AT72 and carbon fibre, 2.2 mm is the thickness given to the model of door. Fig. 11 shows the effect of mass reduction by these changes.

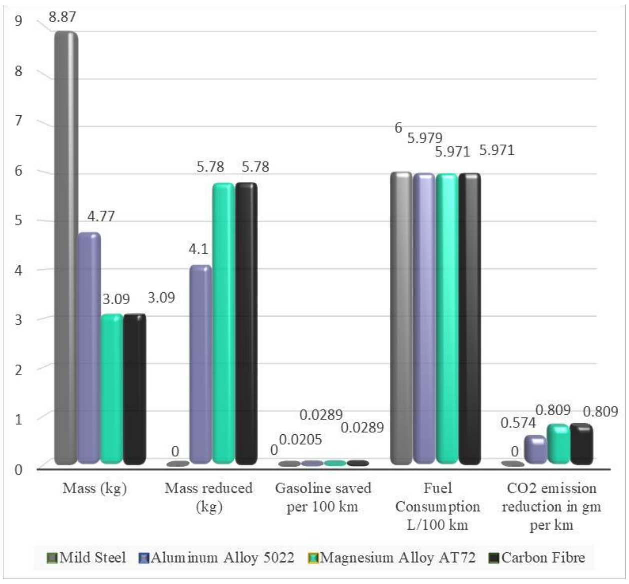


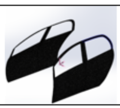
Fig. 11. Representing The Effect Of Mass Reduction Of Front Left Door

6.1.2 Considering four doors

The mass of front left door and the front right door considered approximately same. However, there is a difference between the front and rear doors. The rear doors are lighter than the front doors. Four doors are considered, and different materials are applied. The thickness of the doors assumed same as applied earlier i.e., 1.4 mm for mild-steel, 2.2 mm for aluminium alloy 5022 and magnesium alloy AT72 and carbon fibre. The weight of the doors with mild Steel is coming out to be 32.16 kg. Aluminium alloy 5022 applied as door material with thickness of 2.2 mm and mass reduced from 32.16 kg to 17.39 kg. Magnesium alloy AT72 applied as door materials and more reduction in weight observed. The weight of the door now reduced from 32.16 kg to 11.27 kg. In the case of carbon fibre, the weight of the door now reduced from 32.16 kg to 11.27 kg, which is the same mass reduction as obtained in the case of magnesium because both the materials have same density. The results tabulated and summarised below in Table 3 and Fig. 12.

Table 3

Showing mass reduction's effect of four doors

Door models	Material	Mass (kg)	Mass reduced (kg)	Gasoline saved per 100 km	Fuel Consumption L/100 km	CO_2 emission reduction in gm per km
	Steel	32.16	-	-	6.000	--
	Aluminium alloy 5022	17.39	14.77	0.0739	5.926	2.068
	Magnesium alloy AT72	11.27	20.89	0.105	5.896	2.925
	Carbon Fibre	11.27	20.89	0.105	5.896	2.925

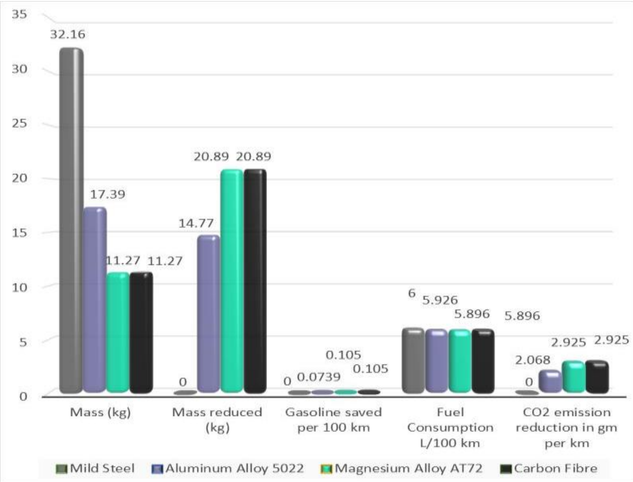


Fig. 12. Representing the effect of mass reduction of four doors

6.2 Considering the Complete Car's Model with Four Doors

Now the complete model of body in white is considered and doors assembled in the model. Firstly, mild Steel doors are considered, and the result given in Fig. 13. The complete mass of the model is coming out to be 58.78 kg, the material of the doors is mild Steel, and the material of the remaining body is used as standard material, and the material is used to model the bumpers is given as plastic.

Now, aluminium Alloy 5022 doors assembled in the model with the remaining body material as mild steel. The mass of the complete model is coming out to be 44.01 kg. Now, the magnesium Alloy AT72 doors assembled in the model and the mass of the model is now coming out to be 37.89 kg. The calculated and compared values presented and summarised in the Table 4 and Fig. 14.

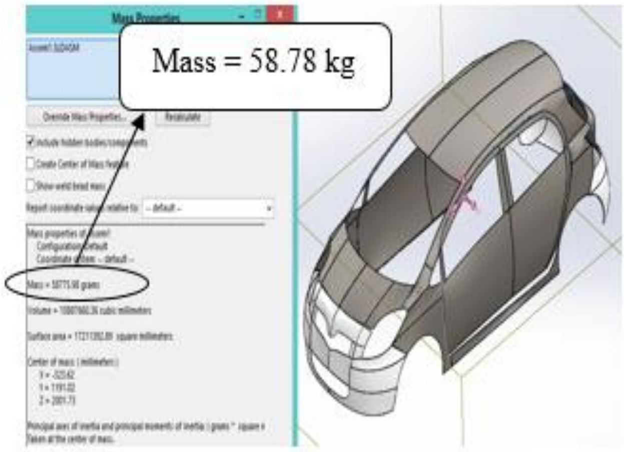


Fig. 13. Showing the complete model, the applied door material is mild steel

Now, aluminium Alloy 5022 doors assembled in the model with the remaining body material as mild steel. The mass of the complete model is coming out to be 44.01 kg. Now, the magnesium Alloy AT72 doors assembled in the model and the mass of the model is now coming out to be 37.89 kg. The calculated and compared values presented and summarised in the Table 4 and Fig. 14.

Table 4

Showing mass reduction's effect of four doors assembled in model

Door models	Material	Mass (kg)	Mass reduced (kg)	Gasoline saved per 100 km	Fuel Consumption L/100 km	Fuel consumption and monetary efficiency (*267.34 PKRs/L) as of 16th Dec-2023	CO_2 emission reduction in gm per km
	Steel	32.16	-	-	6.000	-	--
	Aluminium alloy 5022	17.39	14.77	0.0739	5.926	19.756	2.068
	Magnesium alloy AT72	11.27	20.89	0.105	5.896	28.070	2.925
	Carbon Fibre	11.27	20.89	0.105	5.896	28.070	2.925

6.3 Centre of Gravity

The centre of gravity plays an important role in dynamic stability of a vehicle. [35] The lower the centre of gravity, more stable the vehicle is. As reducing the mass of the doors i.e., outer components mass is being reduced. As a result, the centre of gravity shifts more towards the inner side. This shift in centre of gravity improves the dynamic stability of the vehicle. From obtained results, the position of centre of mass in different applied materials discussed here. Table 5 shown is the results of the shift in the centre of mass when the door material is changed, and lighter materials are applied.

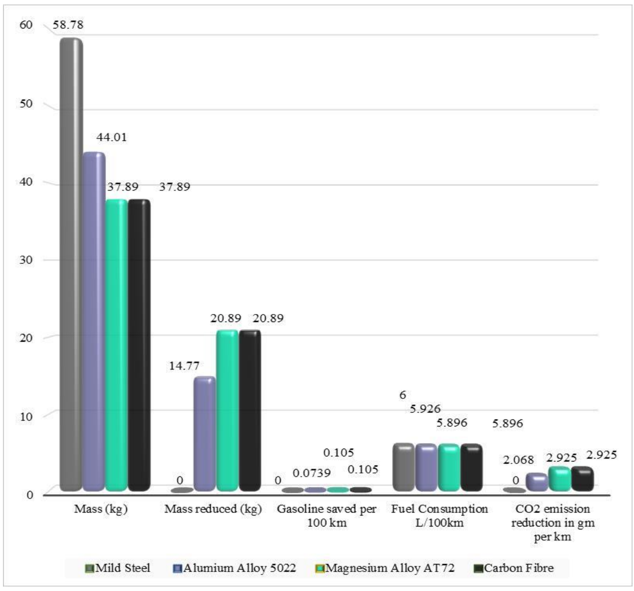


Fig. 14. Representing The Effect of Mass Reduction Of Four Doors When Assembled In Model

Table 5

Showing mass reduction's effect of four doors on centre of gravity

Door Material	Centre of Mass (in meters)		
	X	Y	Z
Mild Steel	0.324	1.191	2.001
Aluminium Alloy 5022	-0.810	2.700	4.440
Magnesium Alloy AT72	-0.810	2.700	4.440
Carbon Fibre	-0.120	1.360	1.820

6.4 CO_2 Emission Reduction

CO_2 emission is a big problem faced by automakers as well as by the society.[36] Different fuels emit different amount of CO_2, depending upon their carbon content. As one litre of petrol weighs 750 grams and petrol is consisted of 87% carbon, which means 662 grams of carbon per litre. To combust this amount of carbon to CO_2, 1740 grams of oxygen is required. Therefore, the amount of CO_2 will be 2392 g/L of petrol. The average consumption of selected vehicle is 6 L /100 km, which corresponds to 6 × 2392 g/L/100 km = 143 g CO_2/km. The reduction in CO_2 emissions shown in Fig. 15 by considering one door, four doors, and finally assembled car model with four doors. When replacing mild Steel by aluminium as door material, then there is reduction in CO_2 emission. This reduction is 2.086 g CO_2/ km. Therefore, the overall CO_2 emission will become 140.9 g CO_2/km. When replacing mild Steel by magnesium alloy or carbon fibre as door material, then there is reduction in CO_2 emission. This reduction is 2.925 g CO_2/ km. Therefore, the overall CO_2 emission will become 140 g CO_2/km. More reduction in CO_2 is also possible if other parts of the vehicle considered for mass reduction. By adopting this procedure, reduced the CO_2 emission and can reduce fuel consumption as well. As a result, the dynamic stability of is also improved.

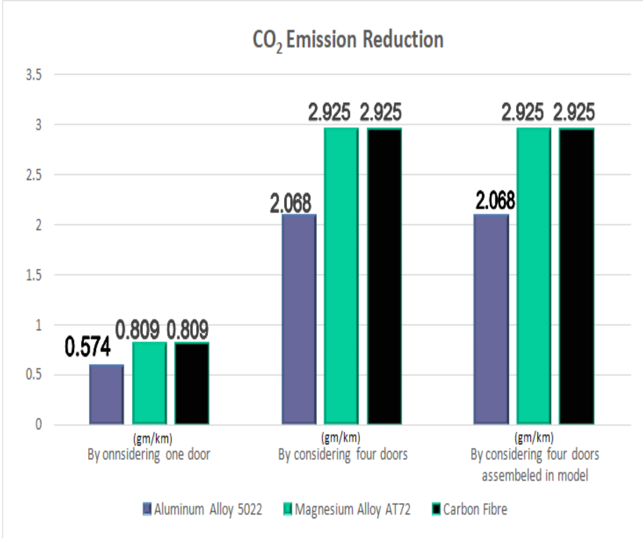


Fig. 15. Representing the reduction of CO_2 emissions

7. Some Comments on Weight Reduction of a Four-Door Passenger Car

In this research, CAD results along with experimental analysis was performed using different material including Steel, Aluminium, Magnesium and Carbon Fibre to see the reduction in weight of a 4-door passenger vehicle. However, there were two significant factors that depict the rigidity of materials taken into consideration: stiffness and performance, which are given in the following analysis as:

7.1 Stiffness Calculations on Door Specimen

The calculation of stiffness was helpful in understanding the material change from the safety perspective. During the test, Steel was compared with Aluminium to calculate the difference between stiffness of both the materials. For this purpose, a force of 500 N was applied simultaneously on Steel and Aluminium, respectively. Due to the applied force, each material bent differently, this was expected due to differing rigidity and toughness. During experimentation, when a force of 500 N was applied, the area was kept constant so as to keep the measurements same for the materials. The area was set as A = 0.227 m^2. Since Steel is more rigid compared to Aluminium, upon applying the force, the former bent 0.066 mm whereas the latter bent 0.068 mm – slightly higher. Thus, from the calculations, the stiffness of steel and aluminium materials were obtained K_{Steel} = 7462 N/mm and $K_{\text{Aluminium}}$ = 7352 N/mm respectively.

7.2 Performance

Performance demonstrates the ability of a vehicle to move its mass effectively. For this purpose, performance was measured using power-to-weight ratio (PWR) that highlights the amount of power required to move per kilogram of vehicle mass. The comparison was carried out between Steel and Aluminium, respectively, as shown in calculations below. The curb weight of the vehicle considered was 1295 kg and had a maximum power output of 98.4 kW. The weight calculations were performed for one door for both steel and aluminium materials due to the fact that the remaining doors portrayed the same dimensions. Thus, from calculations in the previous section, it transpired that door with Aluminium material decreased from 20 kg (in Steel) to approx. 13 kg with Aluminium. Therefore, multiplying with four, we get approx. 52.7 kg of new mass for four doors combined. Thus, the PWR for steel and aluminium materials were calculated as PWR_{Steel} = 0.076 kW/kg and $PWR_{Aluminium}$ = 0.079 kW/kg respectively. Therefore, from the above calculations, it became clear that power-to-weight ratio increased with the decrease in overall vehicle weight, meaning that by using light weight material, the performance of vehicle was improved.

8. Conclusion

In this research, CAD modelling was applied to all four doors of automotive vehicle, which demonstrated a mass savings of the overall vehicle weight reduction of approximately 45% when used Aluminium, 64% when used magnesium and carbon-fibre materials compared with total weight of four doors made of steel martial. By replacing steel with aluminium alloy 5022 as a door material, saving of 0.0739 litres of fuel per 100 kilometres and 2.068 grams of CO_2 per kilometres was calculated. Moreover, by replacing steel with magnesium alloy AT72 or carbon fibre, a saving of 0.105 litres of fuel per 100 kilometres and 2.925 grams of CO_2 per kilometres was measured. The results obtained through research results would be helpful for automakers to overcome the CO_2 emissions. When the weight of the car was reduced from outer side i.e., doors, its centre of gravity shifted more towards the inner side. Hence, strengthening the handling and dynamic stability of a vehicle. Moreover, the bending stiffness of Steel and Aluminium was also taken into consideration to analyse vehicle safety, which showed that although Steel was brittle but costly; however, Aluminium had an advantage of low cost with good rigidity to be used as the door material. Moreover, from the calculations, it turned out that the difference between bending stiffness of steel and aluminium was not very high, which made aluminium a good selection for consideration. Subsequently, the performance of both materials was measured in terms of power-to-weight ratio (PWR), which also highlighted that aluminium was better in terms of its vehicle power consumption with a PWR of 0.079 kW/kg, with steel which had a PWR of 0.076 kW/kg. This demonstrated that the use of light material was in favour of saving furl mileage, CO_2 emission, and increased PWR. Results obtained in monetary value showing significant economic efficiencies of almost 19.756 PKRs/L in case of Aluminum alloy 5022, 28.070 PKRs/L in case of Magnesium alloy AT72 and 28.070 PKRs/L in case of Carbon Fiber. By 2025 the electrical vehicles are expected to be 35% of the current as of 2019, where significant proportion of the skateboard chassis and batteries covers are proposed to be made of Aluminum, magnesium and CFRP.

9. References

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