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Lightweight Composite Applications in the Structural Design of Quadricycles

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Review Article

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Abstract

Due to the increasing number of internal combustion engine vehicles, fossil fuel sources have decreased drastically in the last century. In addition, the concerns about global warming caused by vehicle emissions have led automotive manufacturers to search for new alternatives to transport. Quadricycles have started to be seen as future transport vehicles due to their smaller design and lower energy consumption when compared to conventional vehicles. Furthermore, they are also considered to prevent increasing traffic jams in metropolitan areas. The lightweight design of a quadricycle is crucial since its weight would affect energy consumption. On the other hand, because of their minimalistic design, crashworthiness is another factor that must be considered in the structural design of quadricycles for the safety of occupants in case of a collision. Composites are one of the most promising materials for manufacturing lightweight structures due to having a high strength-to-weight ratio compared to conventional metals. In this study, different body designs and optimizations of quadricycles are introduced. Comparisons are made between conventional metals and composite materials used in quadricycles in terms of weight and stiffness. Studies showed that a 15% increase in specific energy absorption capability and a 50% weight reduction at the same time is possible by using composite materials rather than metals in the design of structural parts.

Keywords: Composite material; Crashworthiness; Lightweight design; Quadricycle

1. Introduction

In the last century, the transport need of people has increased substantially owing to a major increase in the world population, and this situation led to global vehicle ownership increasing. As a consequence of the growth in the population, personal vehicles with internal combustion engines (ICEs) have led to some issues such as increasing traffic jams, scarcity of parking lots, health problems because of air pollution, and noise pollution, especially in metropolitan areas. [1]. In 1950, 30% of the world's population was living in urban areas. As of 2014, the world population living in urban areas reached 54%, and by 2050, it is expected to be 66% according to UN predictions. Since people continue migrating from rural areas to urban areas because of the various opportunities for education and employment that cities provide, it can be expected that these mentioned problems in metropolitans to expand day by day [2]. The increment of conventional personal vehicles providing at least four passenger seats, comfort, and quality has created a problem of increasing CO_2 (carbon dioxide) emissions which causing global warming. According to Intergovernmental Panel on Climate Change (IPCC), the temperature of the earth could increase up to 5ºC by 2070 because of CO_2 emissions unless some precautions are taken to reduce emissions. Because of the growing environmental concerns and awareness, the production of electric vehicles (EVs) has been ramped up since they do not have any exhaust emissions. However, the driving range of EVs without a recharge is unsatisfactory due to the limited battery capacity [3]. Rising fuel prices, strict regulations for reducing CO_2 emissions, and short travel distances of electric vehicles have pushed manufacturers to design small and lightweight vehicles to achieve emission targets and less energy consumption [4]. Recently, quadricycles (also called microcars), which are four-wheeled motorized vehicles, have emerged as a novel solution for personal transportation. These compact vehicles are derived from motorcycles and have a frame structure that protects occupants against collisions [5]. A quadricycle generally carries at most two people, unlike traditional vehicles which are five. Moreover, quadricycles have significantly different characteristics than conventional vehicles in terms of dimension, acceleration, and maximum speed [6]. There is a comparatively narrow space between the occupant compartment and the exterior of quadricycles owing to their small size and this leads to a significant risk for occupants in case of a collision with larger vehicles [7,8]. In order to achieve an adequate level of safety for the occupants in collisions, and a lightweight vehicle, material selection has a key role in the design of quadricycles.

2. History of Quadricycles

Despite quadricycles have become popular in recent years, the history of these compact vehicles goes back to 1980s. The first quadricycle was developed by Henry Ford in 1986, and it was a simple frame car which four bicycle wheels mounted on it. Ford's quadricycle is shown in Figure 1.

Fig. 1. Henry Ford sits in his first automobile, the Ford Quadricycle in 1986 [9]

After Ford's first quadricycle, the cyclecars that are smaller, lightweight, and inexpensive versions of conventional four-wheeled cars were produced between 1910 and the early 1920s. The goal of cyclecars was to fill the position in the market between cars and motorcycles. Cyclecars were generally propelled with two-cylinder air-cooled engines and the cyclecar makers sometimes used motorcycle engines. These vehicles became highly popular, and the number of cyclecar makers increased quickly in many countries such as the UK, France, Germany, and other European countries. However, these vehicles were neither safe nor comfortable as conventional vehicles since many of them had narrow spaces that only accommodate two passengers. Cyclecars started losing their popularity after larger cars such as Austin 7, Citroën 5CV, or Morris Cowley became more affordable, and most of the manufacturers producing cyclecars shut down [10]. In the 1950s and 1960s, quadricycles were also called bubble cars by the general public. Messerschmitt KR175 was one of the first examples of bubble cars built with a single-cylinder engine by Messerschmitt in 1953. BMW Isetta was developed in 1955 and is one of the best-selling bubble cars of all time. In 1956, Heinkel Kabine 153 (three-wheeler) was developed by Ernst Heinkel, with a four-stroke motor. The three-wheeled Peel P50 was made in 1962 by Peel Engineering Company. On the other hand, Recent quadricycle examples are Tazzari Zero, Renault Twizy, and Citroen Ami which are all electric-powered vehicles [11]. Figure 2 illustrates Citroen Ami and Renault Twizy.

Fig. 2. Citroen Ami (on the top) and Renault Twizy (at the bottom)

3. Classifications and Definitions of Quadricycles

A global vehicle classification does not exist for quadricycles. However, there are different approaches in different regions to categorize quadricycles according to the limitations of the design of these vehicles such as weight, dimension, and power. In Europe, the classifications for vehicles category are based on United Nations (UN) Regulations, also known as United Nations Economic Commission for Europe (UNECE) standards. Quadricycles are included in Category L: light motor vehicles, according to the EU classification of motor vehicles. In addition, the framework Directive 2002/24/EEC improved the definition of quadricycles by separating them into two sub-categories, known as: light quadricycles (L6e) and heavy quadricycles (L7e). The technical specifications of L6e and L7e category vehicles are defined by Framework Directive 2002/24/EC as follows [5];

Light quadricycles (L6e) are:

- four-wheeled motor vehicles
- whose unladen mass is a maximum of 350 kg, the mass of the batteries is excluded in the case of EVs

- whose engine cylinder capacity does not exceed 50 cm³ for spark ignition engines
- maximum net power output does not exceed 4 kW in the case of an ICE
- maximum continuous rated power does not exceed 4 kW in the case of an electric motor
- whose maximum speed is not more than 45 km/h

Heavy quadricycles (L7e) are:

- four-wheeled motor vehicles other than those referred to as light quadricycles
- whose unladen mass is a maximum of 400 kg (or 550 kg for vehicles carrying goods), the mass of the batteries is excluded in the case of EVs
- maximum net power output does not exceed 15 kW in the case of an ICE
- maximum continuous rated power does not exceed 15 kW in the case of an electric motor
- whose maximum speed is not more than 90 km/h

Table 1. EU Classification of Quadricycles [5]

Category	Subcategory	
L6e (Light Quadricycle)	L6e-A	Light quad
	L6e-B	Light mini car
L7e (Heavy Quadricycle)	L7e-A1	On road quad
	L7e-B1	Heavy all-terrain quad
	L7e-B2	Heavy all-terrain quad side-by-side buggy
	L7e-C	Heavy Quadri-mobile

In the United States of America, quadricycles are categorized as Low-Speed Vehicles (LSV) according to the regulations of the safety standard FMVSS 500. These vehicles are limited to 40 km/h maximum speed and 1361 kilograms maximum weight. Another category of small vehicles is Japanese minicars which were introduced in 1949. Several revisions have been made to the specifications of minicars, and manufacturers are obligated to follow limitations on the dimensions and power of the vehicle in Japan [12, 13].

4. Design

The chassis can be defined as a frame like a skeleton where all other parts of a vehicle such as the steering system, engine, and power train are assembled on it. The fundamental task of a chassis is to ensure rigidity and strength to a vehicle [14,15]. Generally, there are two main types of structures preferred in the production of vehicles based on the relation between the frame and the body. Nowadays, integrated frame and body structures which are called monocoque or unibody, are mostly used in vehicle production. Body on frame is another type of structure in which the body and chassis are included separately and used for the production of vehicles. Space frames and ladder frames are among the body-on-frame structures which some electric vehicles use these types of chassis. [16]. A typical ladder frame and monocoque chassis are demonstrated in Figure 3.

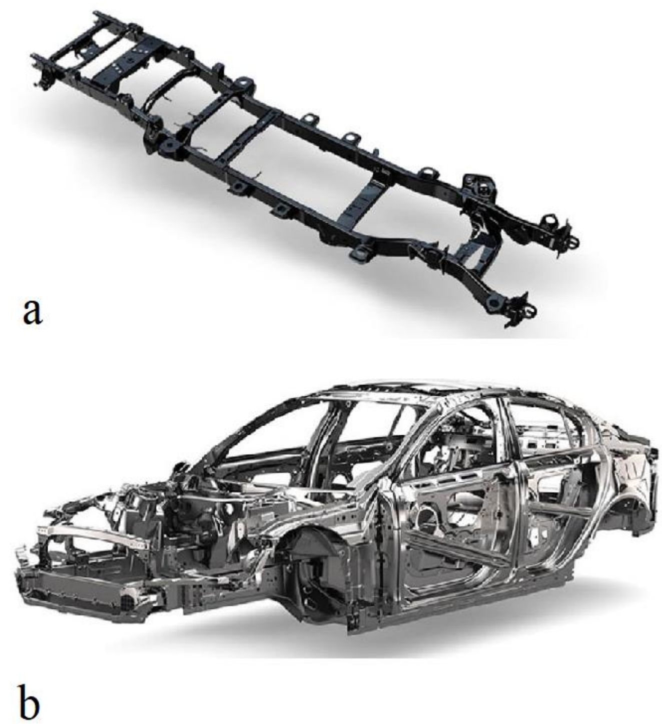

Fig. 3. Chassis types used in vehicles; a) ladder frame, b) monocoque chassis

Electric vehicle chassis generally consist of an electric motor, a motor controller, and a battery pack. In general, the chassis of EVs resists various loads including torsional loads, bending loads, longitudinal loads, and lateral loads that occur in case of acceleration and braking [17]. There are prominent differences between the design of EVs and ICE vehicles. For instance, a slightly heavier chassis is not important in ICE vehicles since extra weight can be compensated by adding a bit more power [18]. However, a lighter design is required in electric vehicles since an increase in the weight of an EV leads to a decrease in the travel range without a recharge owing to battery limitations. In addition to being lightweight, the chassis of an EV must also be rigid because it is the most important part of providing safety [14]. The use of innovative materials for the chassis, combined with the robust design, can meet the desired safety, weight, and production cost [15]. There are also similar requirements for designing quadricycles which are small vehicles mainly designed to commute in urban areas. According to ECE R 618 standards, overall dimensions of L6e category passenger quadricycles must not exceed a length of 3000 mm, a width of 1500 mm, and a height of 2500 mm [19]. Nowadays, most of the manufactured quadricycles are electrically powered in order to overcome the global warming problem by reducing oil dependency and harmful vehicle emissions. Battery technology has a significant effect on the development of an electric vehicle. Because electric quadricycles do not possess areas as large as conventional EVs, they usually have small battery packs. Therefore, electric quadricycles have limited driving ranges and are not proper vehicles for very long distances. Since energy requirement will decrease when the vehicle is lighter, the lightweight design of the quadricycle becomes one of the key parameters that determine the energy consumption, particularly in city conditions during acceleration and deceleration of the vehicle [20,21]. Although electric motors are generally preferred in these vehicles, different kinds of engines are also used very often [22]. Three different versions of these vehicles with three different drivetrain layouts are demonstrated in Figures 4 to 6.

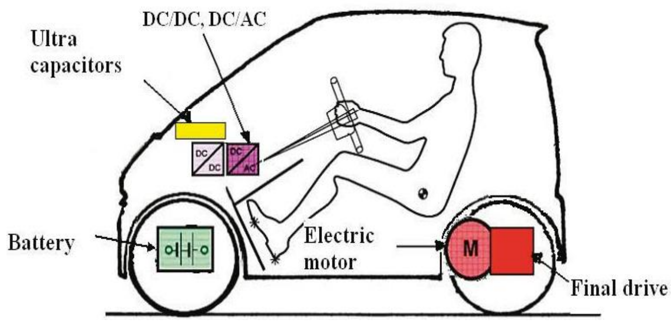

Fig. 4. First version of a drivetrain layout [22]

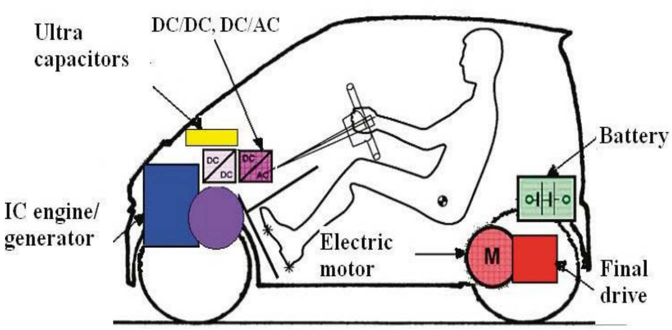

Fig. 5. Second version of a drivetrain layout [22]

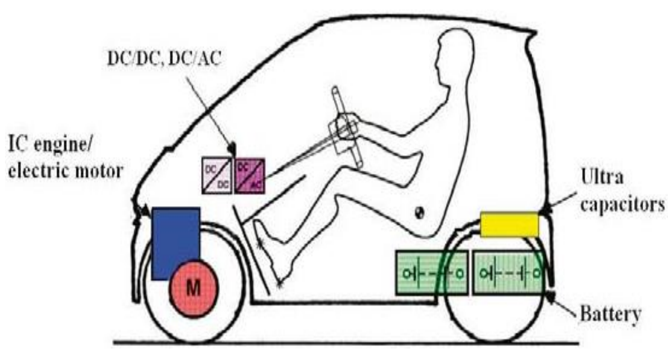

Fig. 6. Third version of a drivetrain layout [22]

Since a vehicle consists of thousands of parts, dozens of kilograms can be saved by reducing the weight of each part, even a few grams. The body is one of the most important parts of the vehicle that can alter the total vehicle weight quite a lot. Therefore, it is essential to design the body from light materials to reduce the weight of the vehicle. In addition to that, expensive materials should be avoided to keep the cost low. In this sense, composite body panels have been designed and manufactured by various researchers. In some of these applications (Figure 7), fiber-reinforced plastics (fiber-glass structures) were preferred since they provide an optimum balance between lightweight, strength, and cost [20].

Fig. 7. Fiber-glass body structure of an L7e vehicle; Hu-Go [20]

On the other hand, due to their small size and lightweight, quadricycles are more vulnerable than conventional vehicles in case of car-to-car collisions [23]. In addition, there is no safety regulation for quadricycles to comply with, and Euro NCAP's test also proves that quadricycles have a much lower level of safety than conventional passenger cars. Therefore, the chassis of a quadricycle must also be stiff to provide a convenient level of safety for the passengers. In summary, an ideal small urban vehicle chassis/body should fulfill the following criteria [18]:

- rigid
- lightweight
- robust
- vibration-free
- resistant to impact
- easy to produce
- inexpensive
- corrosion proof

Various design applications for quadricycles have been carried out by researchers, and aluminum is one of the most common materials used in lightweight chassis design [24]. In order to achieve further weight reduction while keeping the rigidity of the quadricycle, composite chassis especially made of carbon fiber reinforced plastics (CFRP) which can offer a high strength-to-weight ratio, have been designed by several manufacturers [25,26]. Lately, carbon fiber composites are being highly preferred over conventional metals due to having many advantages. There are also several composite materials such as para-aramid (kevlar), E-glass and basalt fiber which utilized in production of vehicle parts. In order to evaluate advantages of composite materials when compared to metals, the specific properties of some fibers and conventional metals are presented in Table 2.

Table 2. Specific properties of some fibers in comparison with conventional metals. Reproduced from [27]

Materials	Density (g/cm³)	Specific Strength (N.m/kg) σ/ρ	Specific modulus (N.m/kg) E/ρ	Extension to Break (%)
Stainless steel	7.9	0.22-0.28	27	1.5-11
Aluminum	2.7	0.05-0.23	25.92	-
Carbon fiber HM	1.83	1.2	256	0.7-1.7
Para-Aramid HM	1.44	2	80	2.4
E-Glass	2.58	0.775	28	4
Basalt CBF	2.65	0.75	32	3.4

ρ : Density, σ : Tensile strength, E : Young's modulus, HM : High modulus, CBF : Continuous basalt fiber

5. Materials

Material selection in a vehicle body design is crucially important since it directly affects the vehicle weight and crashworthiness. Most parts in vehicles are manufactured from steel, aluminum, and magnesium in the automotive industry. Due to the increasing concerns on environmental protection and sustainability, lightweight material usage has become one of the main goals of manufacturers since fuel consumption, exhaust emissions, and energy consumption in the case of EVs can be reduced by manufacturing components from lighter materials [28]. Composite materials, which are widely known as the combination of at least two materials in a common matrix that results in better properties, have become more often preferred materials in the automotive industry in recent years. Although there are various types of composite materials, fiber-reinforced polymer (FRP) composites which consist of fibers as the reinforcement and polymers as the matrix, are primarily utilized [29]. While the reinforcement element which is a fiber provides strength and stiffness, the matrix which is a polymer maintains the fibers in the proper orientation and protects them from environmental damage [30]. A typical composition of a composite material is shown in Figure 8.

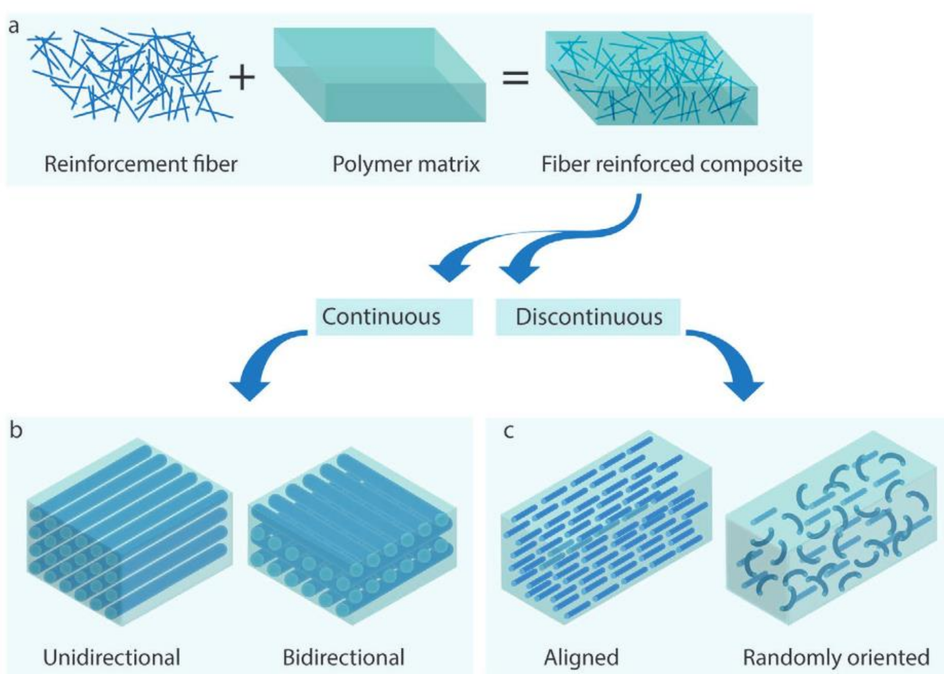

Fig. 8. The general structure of FRP composites and their classification: a) Basic constituents of FRP composites, b) continuous FRP composites: unidirectional and bi-directional, and c) discontinuous FRP composites: aligned and randomly oriented composites [31]

In fiber-reinforced composites, continuous fibers are utilized more than discontinuous ones since they demonstrate higher strength and stiffness. This can be explained as continuous fibers have long aspect ratios and a preferred orientation (aligned) whilst discontinuous ones have short aspect ratios and a random orientation. In addition to that, epoxy resins are one of the most common matrix materials for high-performance composite applications [32]. FRP composites are constantly becoming a more popular choice due to having many advantages including fatigue resistance, lightweight, corrosion resistance, high strength-to-weight ratio, and ease of formability. They are also more sustainable and able to be manufactured in large quantities. There are two types of fiber used in FRP structures which are synthetic and natural fibers. Synthetic fibers, mostly carbon fibers, are heavily utilized in fiber-reinforced composites because of their unique mechanical properties in high-performance and lightweight applications [33]. Therefore, comprehensive studies have been conducted on composite applications in vehicle parts, and promising results have been obtained. For instance, a research result showed that a 50% weight reduction could be obtained by using CFRP composites rather than steel. In the BMW i3, a 30% weight reduction has been achieved using CFRP composites in internal parts and body structure [34]. In addition to weight reduction applications, the crashworthiness and specific energy absorption capabilities of composites have been investigated and better results were obtained when compared to conventional metals. [35,36]. However, synthetic fibers have a high cost, require lots of energy to produce, and are not environmentally friendly. These issues of synthetic fibers have led researchers to develop effective novel materials by taking advantage of natural fibers because they are eco-friendly, bio-renewable, and easily available at a lower cost than synthetic counterparts and also offer good strength. Many automotive companies have begun to use natural fiber-reinforced composites (NFRCs) in various vehicle parts including door panels, seat backs, dashboards, etc. due to these advantages of natural fibers [37].

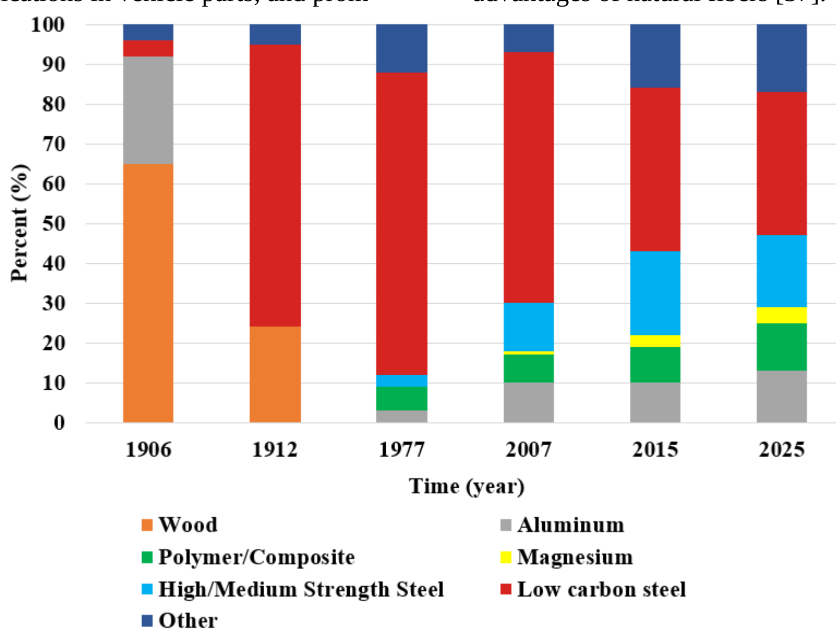

Fig. 9. Historical shift in vehicle composition by mass. Reproduced from [38,39]

6. Applications

The promising results obtained by using composite materials in conventional vehicles have encouraged researchers and manufacturers to apply composites in quadricycle design. Boria et.al. introduced a study on thin-walled cylindrical tubes and frontal impact attenuators (crash boxes) produced with both aluminum and carbon fiber reinforced plastic (CFRP) composites to determine the best option in terms of specific energy absorbing (SEA) capacity while maintaining the lightweight design of a microcar. The experimental tests were performed using a drop-weight test machine for thin-walled cylindrical tubes and crash boxes with different thickness/diameters. All the experimental tests were conducted using a drop weight test machine with a 6 m free-fall height and a maximum mass of 413 kg. An impact mass of 294 kg and an initial velocity of about 4 m/s were used for these tests on cylindrical tubes. After six different tests, the results demonstrated that the SEA capacity of CFRP tubes was 25 to 145% higher than aluminum ones. In the case of the impact attenuators, the six different versions of impact attenuator were tested at the same impact conditions. Test results showed that although crash-boxes that made of CFRP composites absorbed less energy than aluminum ones, they had 5 to 15% higher SEA values than aluminum counterparts due to having %50 less weight, approximately [24].

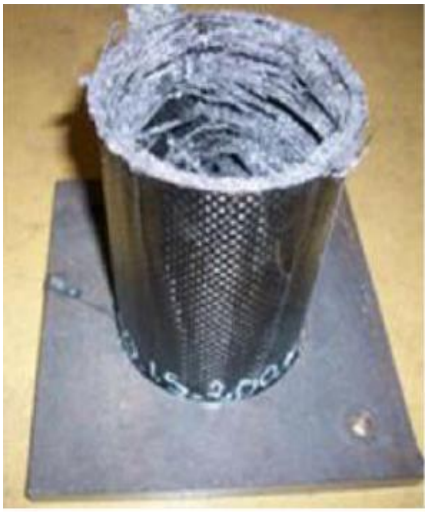

Fig. 10. A deformed CFRP tube after the test [24] (Copyright © 2015 Inderscience Enterprises Ltd.)

The Institute for Automotive Engineering of RWTH Aachen University introduced a development of a lightweight L7e vehicle prototype for sustainable urban mobility. The space frame of the vehicle was manufactured from CFRP composite structure and aluminum in order to fulfill the lightweight and safety requirements. Moreover, a real vehicle crash test was performed at 50 km/h on a rigid wall with respect to the Euro NCAP test protocol in addition to a simulation test. The crash vehicle consists of the CFRP-Al-Space-Frame structure including the chassis and masses of drivetrain, battery as well as package components weights. The overall vehicle weight was 600 kg and loaded with a 75 kg H3-dummy, which represents an average male driver. The structure of the space frame demonstrated only minimal intrusion in the simulation and the real crash test. The test result validated the simulation and showed that a small electric vehicle could achieve good structural as well as good occupant safety [25]. Galmarini et al. introduced the design and construction of GreenFun which is a light quadricycle. The chassis of the vehicle was composed by two main parts: a monolithic CFRP survival cell and an aluminum alloy sub-frame. The sub-frame has been realized by using two different aluminum alloy profiles. A sandwich structure made of CFRP and aluminum honeycomb has been created in order to increase stiffness and the main frame is completed by a monolithic CFRP survival cell. The remaining parts of the quadricycle were made of fiberglass, and then connected to the mainframe. In order to evaluate the torsional stiffness, three different FEM analyzes have been performed starting from the sub-frame, then the sandwich structures, and finally the complete frame. FEM results showed that although the mass of the composite chassis was very low, the torsional stiffness was similar to that of a standard middle-class car [26]. Romo et al. introduced a development of an L7-class urban electric vehicle with three different structures to evaluate the crashworthiness of the vehicle. These structures were based on a CFRP composite, a high-strength steel, and a multi-material including aluminum, magnesium, and thermoplastic. The aim of the study was only to design of structures; therefore, no prototype was built and no real tests have been made. Frontal crash, lateral crash and rear crash simulation tests were performed to CFRP structure. The test results demonstrated that it is possible to design a very light structure by using CFRP and obtain very high stiffness values [40]. Kongwat et al. presented a study on heavy quadricycle structures using CFRP in the passenger cell and aluminum alloy in the crumple zone. In order to investigate structural crashworthiness, the behaviors of heavy quadricycles under several impact conditions were simulated according to the European New Car Assessment Programme (Euro-NCAP) test guidelines using a non-linear FEA (Finite Element Analysis) via LS-DYNA. Full frontal crash analysis of a rigid wall was carried out with diverse initial velocities of 30 km/h, 40 km/h, and 50 km/h. The results showed that the crumple zone could efficiently absorbed and distribute the impact energy. On the other hand, side impact collisions were also performed on the quadricycle, and it was reported that the vehicle tended to overturn in case of a side collision due to its lightweight [41]. In automotive lightweight applications, there is an increasing interest in replacing conventional steel leaf springs with composite leaf springs owing to offering a high strength-to-weight ratio. It is also possible that the weight of the leaf spring can be reduced without any reduction in stiffness and load-carrying capacity. Papacz et al. presented a study on glass fiber-reinforced plastic (GFRP) leaf springs to replace steel leaf springs in a van. In this study, steel leaf springs and GFRP leaf springs were manufactured with the same width and length. After production, the weight of the GFRP leaf spring and steel leaf spring was measured as 12 kg and 50 kg, respectively. Thus, a 76% of weight reduction was achieved by replacing steel with a GFRP counterpart. Also, a comparison on vibration suppression properties of composite leaf springs and steel leaf springs was made in this study. The results showed that the vibration suppress ability of composite leaf springs was three times greater than steel leaf springs. [42].

Fig.11. Composite leaf spring [42]

Similar to this application, Ferrais et al. presented a feasibility study for quadricycles by focusing on vehicle dynamics, structural integrity, and lightweight. A transversal leaf spring suspension was manufactured from CFRP, and an aluminum space-frame was preferred in order to achieve a lightweight design [43]. Carello and Airale presented a study on a composite-based suspension system for XAM 2.0, which is a heavy quadricycle prototype. A carbon fiber suspension arm was designed and manufactured instead of an aluminum one which exists on the vehicle XAM 1.0 in order to achieve low energy consumption. The results showed that the carbon fiber suspension had 5% less weight and 78% higher stiffness when compared to the aluminum one [44]. Fantuzzi et al. presented a study to evaluate the applicability of bio-composites in the rear and front bumper of a microcar as an alternative to glass and carbon fiber-reinforced composites. Four different flax-based bio-composites were manufactured, and the mechanical properties of these composites were determined. A finite element modeling was performed to test the mechanical behavior of the components. The test results indicated that flax-based bio-composites were very promising for use in automotive components [45]. Valladares et al. developed a frontal composite structure for L7e vehicles. The aim was to satisfy the requirements of energy absorption for pedestrian protection. A glass fiber composite structure was produced as a prototype, and an impact test was performed on the prototype. The results showed that composite structures had satisfactory energy absorption capacity [46].

Fig. 12. A prototype of the frontal composite structure [46]

Fresnillo et al. also developed a heavy quadricycle (BEHICLE) using composite panels for occupant safety. The external cover of the vehicle was made of a glass fiber composite panel. In addition, the doors, the seats, the roof, and the firewall were also made of composite panels. Euro NCAP crash assessment was performed to the final composite prototypes using the 'year 2013' rating protocols to allow comparison with the baseline crash tests. According to the results, BEHICLE demonstrated an equivalent level of protection in comparison with conventional Supermini cars [47].

7. Conclusions

Since the world population is continuously growing, the prevention of air pollution and global warming becomes more and more challenging every day. The quadricycles are expected to be a novel solution to prevent not only air pollution and global warming but also expanding traffic jams and scarcity of parking lots in metropolitans. Due to the rising popularity of quadricycles, researchers have started to carry out more studies on the design of these small vehicles with alternative materials to reduce weight and obtain crashworthy structures, by keeping the cost as low as possible. In the early stages, aluminum was a dominant material of choice by researchers in lightweight design applications due to being significantly lighter and cheaper than steel. However, lightweight design studies on conventional vehicles showed that fiber-reinforced polymer composite materials can offer even more weight reduction than aluminum, and provide an adequate level of strength. Synthetic fibers, especially carbon fibers, were used heavily in FRP composite structures in the past decade and very promising results were obtained by researchers. In such studies, the results demonstrated that a 50% weight reduction in the design of tubular chassis or a 78% increase in the stiffness of a leaf spring is achievable by using CFRP rather than aluminum. The results of these studies could be considered as a basis for future studies. The development of chassis, crash boxes, suspensions, internal parts and the external body of a vehicle from CFRP composites could even further reduce the overall vehicle weight. For future studies, other composite materials with good specific properties presented in Table 2 such as para-aramid (kevlar), E-glass, and basalt fiber could be utilized for production of the components and real crash tests in addition to simulation tests could be performed in order to evaluate their usability in the design of structural parts.

Nomenclature

ICE	:	Internal Combustion Engine
CO_2	:	Carbon Dioxide
IPCC	:	Intergovernmental Panel on Climate Change
UN	:	United Nations
°C	:	Celsius
EV	:	Electric Vehicle
UK	:	United Kingdom
LSV	:	Low-Speed Vehicles
CFRP	:	Carbon Fiber Reinforced Plastics
FRP	:	Fiber-Reinforced Polymer
NFRC	:	Natural Fiber Reinforced Composites
SEA	:	Specific Energy Absorbing
FEA	:	Finite Element Analysis
GFRP	:	Glass Fiber Reinforced Plastics

Conflict of Interest Statement

The authors declare that there is no conflict of interest in the study.

CRediT Author Statement

Okan Çelik: Investigation, Writing-original draft, Re-sources
Mehmet Murat Topaç: Conceptualization, Writing – review and editing

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