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Lightweight Resources for automobiles manufacturing

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Abstract

Automakers are now motivated to create lightweight vehicles due to the increasing challenges of reducing greenhouse gas emissions and improving fuel economy. Better recyclability and/or vehicle performance may also result from the weight reduction. The expansion and use of lightweight, high-performance resources as substitutes for traditional motorized materials like steel and cast iron is one successful tactic. This paper discusses vehicle lightweighting as a means of promoting better fuel economy and assisting the automotive industry in achieving sustainability. Innovative resources suitable for the constructing of next generation vehicles were reviewed. Advanced high-strength steel (AHSS), aluminum alloys, magnesium alloys, Titanium, polymers, and composite materials frequently utilized for lightweight construction applications were among the cutting-edge materials for the production lightweight vehicles . Categorization, manufacturing methods, physical/mechanical characteristics, and possible uses of particular lightweight ingredients are investigated. A summary of the reviewed materials' benefits and limitations is provided, along with the suitable application scenarios for various lightweight materials.

Keywords

Lightweight materials, Automobile, aluminum alloys, magnesium alloys, composite

INTRODUCTION

The pressure to find creative tools manufacturers in the motorized parts to rise fuel effectiveness and sustainability has been put by many organizations. All new tools are necessary to reach the petroleum low-cost aim according to the Corporate Average Fuel Economy (CAFE) standard based on average weight of the fleet. Lightweight materials contribute to improved fuel economy in vehicles whereas preserving protection and performance. This is due to taking low energy to increase speed of a lighter body than a denser body. Lightweight supplies offer excessive possibility to increase automobile effectiveness. A 10% decrease in car weightiness could lead to a 6%-8% fuel economy enhancement. Substituting old-style steel constituents with lightweight resources like high-strength steel, (Mg) and (Al) alloys, as well as composites may in a straight line decrease the weight of a car's body by more than 50 % leading to decrease an automobile's fuel utilization. It is well-known that the average fleet fuel economy (g / km CO_2 emissions for most countries and regions) of passenger vehicles is difficult to achieve [1]. More specifically, the US established the target for typical CO_2 releases in 2025 to 89 g/km around a 40% reduction over that of 2015[2]. The value of CO_2 emission was detected by the European Union at 95 g/km aimed at 2021, and in the US, for the year 2025, (CAFE) are assigned at 55.8 (mpg) [3].The value of CO_2 emission was detected by the European Union at 95 g/km aimed at the year 2021[3].The UK government has outlined The Net Zero Strategy with an aim to get to net-zero emissions by 2050, leaving no doubt about the importance of electric automobiles [4]. Given the ongoing and expanding environmental safety, lightweighting has been a top choice of manufacturers since curb weight has a significant impact on vehicle fuel consumption (and thus greenhouse gas [GHG] emissions)[5]. While increased fuel economy and decreased emission control will encourage lighter, stiffer, and greener automobiles; higher performance output and recyclability potential over the vehicle life cycle will also lead to most economical design strategies. Thereby, the quest for new materials and a more efficient structural design is an imperative factor of future automobiles. In response, global OEMs have adopted several very effective approaches to meet the challenges, which include aggressively developing hybrid as well as pure electric automobiles [6], improving the drive train efficiency with new technologies [5] and searching for lightweight materials for automobile purposes [7, 8]; among them the greatest attention is paid to weight reduction by virtue of saving cost and energy consumption[9].

Light automobile production in all of the major markets has been growing over the same time period in the past [10] . Lightweight resources for motorized can be mainly classified into four types as possible candidates to substitute old-style engineering resources (such as steel and cast iron), light alloys (e.g., magnesium, aluminum, and titanium alloys), compounds (e.g., carbon fiber reinforced plastics or CFRP) and unconventional resources (such as machine-driven metamaterials). These light-weight ingredients have been widely used in numerous parts of automotive such as, body shell bumper, engine, brake, dashboard controls, suspension structure, gear boxes, navigation system, and battery base since last century [11-14]. Figure 1. shows typical lightweight materials suitable for various automobile components, and Figure 2 illustrates the material composition ratios for standard cars, high-performance motorcycles, and heavy-duty aircraft. In general, the choice of using novel resources on vehicles is not easy and multi-dimensional elements to take for consider. Crucial elements during diverse phases in the sub-processes can significantly affect material choice and design structure, i.e. (1) materials construction (e.g. price, properties), (2) motorized constituent industrial (e.g. structure, surface management and assembly methods), (3) automobile combination (e.g. assembling), (4) lifetime action containing permanency, and lastly (5) recyclability of discarding and releases [15-17]. In this paper a detailed review of the development and application of existing light materials in the automobile manufacturing was provided.

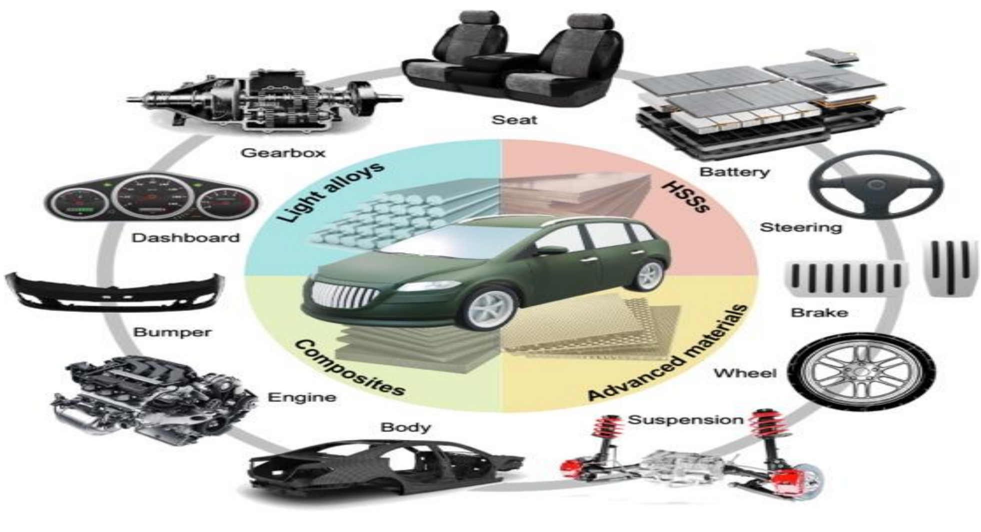

Figure 1. Typical lightweight materials suitable for various automobile components.

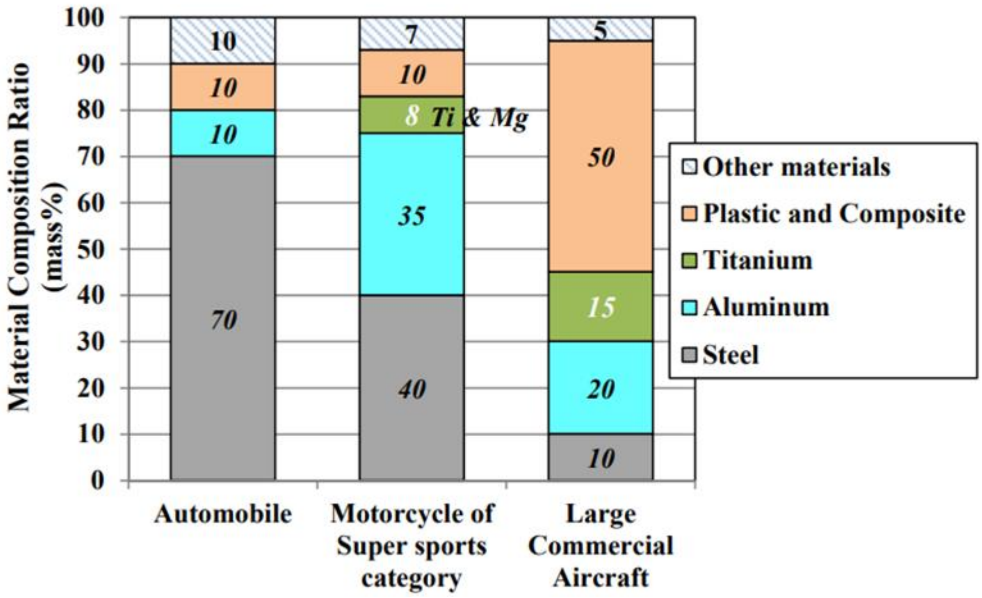

Figure 2. Material composition ratio[39]

STEEL

The steel is used in parts like automobile bodies, machines, chassis, and wheels. Applications typically show reduced weight and structural performance improvements in strength, rigorousness, and other features. It clearly indicates the prospective of steel for efficient manufacturing in creating lighter and harmless automobiles [18]. Up to 55% of the body weightiness in a vehicle is steel. However, there are numerous benefits of steel for many auto body constructions. It possess a great elasticity modulus, one of the uppermost amongst structural resources considered in the automobiles manufacturing. Steel occupies an unrivaled position in present day industry due to its broad strength value (200–1500 MPa), outstanding malleability, good fusion ability and sustainability [19]. The properties evidenced by the steel in sheet form find their application in car body manufacturing, e.g.: high strength and weldability, color ability, good workability and cost effectiveness [20]. The numerous steel types and their distinctive characteristics, as well as their uses in producing diverse components of an automobile's outer body, are outlined as follows:

• Thin sheet, cold-rolled killed (RRST): RRST has a toughness of approximately 270–350 MPa and qualified lengthening exceeding 36%. This type is utilized for manufacturing exterior pieces (hoods, rooftop, entrance, enwalls)

• Thin sheet, boiling steel (UST 1203, UST 1303): having a strong point ranged between 270 to 410 MPa and tensile strain of 28 to 32%. This type is utilized in manufacturing dyed exterior panes and Flooring parts (internal edge, base panels).

• Hot-rolled steel tape (ST 4): characterized by a strong sort of 280-380 MPa, a tensile strain of about 38%; a depth of 1.5-2.5 mm, this material is employed in the creation of components requiring significant thickness and positioned underneath the vehicle exterior [20].

Usage of high-strength steels (HSS) and high-strength low-alloy (HSLA) has increased among automakers in recent years. Ultra-light Steel Auto Body (ULSAB), a type of HSLA steel that is 19% lighter, stronger, and has a lower manufacturing cost, offers superior structural action when compared to traditional steel parts. Ultra- HSS (possess a strong point of $\leq$ 550 MPa) and strength of HSS (ranged from 210 to 550 MPa) are roughly 50% more expensive than conventional steel, but they offer less thickness [21]. Advanced high-strength steel (AHSS) is an exceptional type of steel that possesses a range of application in cars manufacturing because of several properties like its microstructures, high tensile strength, flexibility, in addition to its numerous advantages such as reduced price, weight decrease ability, protective characteristics, decrease greenhouse gas releases and greater recyclability. It is an advanced generation of steel material, which has exceptional strength and is extensively appropriate in vehicles. In the industry of automotive, the implementation of AHSS permits manufacturers and engineers to guarantee total safety, effectiveness, manufacturability, strength, and value of automobiles at a remarkably low expense. Challenges of using AHSS include elevating alloying content of the metal due to increased ductility, and the weldability of AHSS could also destructively affected through the quick heating as well as cooling participating in the welding procedure [22].

ALMINIUM ALLOYS

For lightweighting requests, material density is a crucial factor to consider. Although aluminum has a density that is roughly one-third that of steel, aluminum alloys have a strength-to-density proportion that is comparable to the first-generation advanced high-strength steel (AHSS) value. Additional benefits of aluminum composites include a lesser modulus of elasticity (for absorbing collision energy), formability, machinability, and the fact that substituting to aluminum would often not necessitate extensive reengineering [23].

Aluminum offers weight reduction of more than 50% in comparison to alternative resources in numerous applications. Figure 3 illustrates the distinctive and total weight decreases achieved in key assemblies using aluminum in mass production of cars [23].

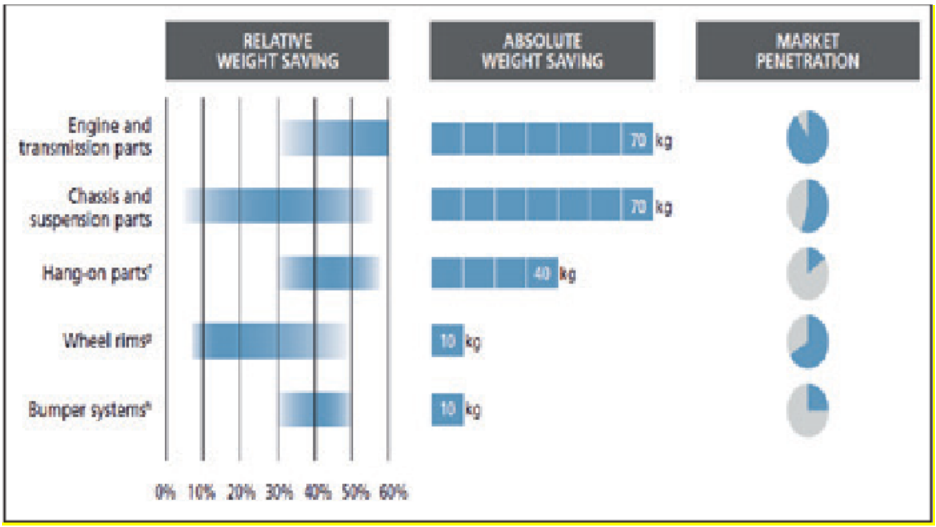

Figure3. Weight reductions with aluminum [23]

Aluminum is a lightweight element with rapid growth. By 2025, European automakers are expected to have an average of 198.8 kg of aluminum per vehicle, whereas premium products from around the world have long since surpassed that amount; for example, content of about 500 kg is found in Jaguar and Land Rover [23]. The Tesla Model S, whose exterior and platform are composed practically completely of aluminum and have an entire Al quantity of 190 kg [24]. Interestingly, the use of aluminum in automobile structure is not novel; for instance, before 1918, Ford's Model T Touring Car made from aluminum surface panels; however, due to lower costs, steel replaced aluminum as the preferred material [25]. The current situation is causing that path to change. Vehicle weight reductions of 30 to 60 percent are possible with the use of aluminum alloys [25]. Using approach of mixing material strategy, Al and AHSS could be utilized together to substitute slight steel. The Ford F-150, for instance, was able to reduce its weight by over 300 kg by mixing an Al body and an AHSS frame [26].

Welding challenges arise when dissimilar metals, like steel and aluminum, are combine due to their different melting temperatures, electrical and thermal conductivity, brittle intermetallic complexes, and possible galvanic erosion. For arc and laser welding, intermetallic mixes are mainly challenging; however, sold-state friction welding yields joints of superior quality, and friction stir welding is particularly practical for extended lined joints. For different joint uses, friction stir spot welding was similarly created as an alternative to resistance spot welding. In spite of its drawbacks, welding is still favored over adhesive bonding and riveting because the latter two methods necessitate overlap, which adds weight. Additionally, they have longer assembly cycle times and provide less joint strength [27].

Determining approaches which can reduce the quantity of aluminum that becomes waste material is essential because aluminum is becoming more and more important in the automotive industry. Aluminum may be regarded as a stable material [28], meaning that it does not substantially degrade during the recycling cycle and retains its inherent qualities. Because of this, using aluminum can support the spherical economy. Making Low-density aluminum sheets or extruded shapes from non-reusable aluminum scrap which can be utilized in the manufacture of vehicles is one concept for closing the production cycle [29].

MAGNESIUM

The lightest structural automotive alloy is magnesium, which has a density of 1.74%, which is lesser than 1/4th of the density of steel. Magnesium and its alloys' exceptional precise strength and stiffness have led to the development of automotive materials with enormous weight-saving prospective. Magnesium was first used to make a transmission housing for the Volkswagen Beetle's air-cooled engine in the early to mid-1930s [30, 31]. Magnesium is presently the third best common metallic component found in cars [30]. Powertrain systems, chassis, and body structures are all examples of main automotive uses [32].

Despite its appealing mechanical and physical qualities, such as high resistance and strength, the price and durability prevent automakers from using it in anything other than high-end models [33]. Magnesium and aluminum have similar tensile yield strengths, but magnesium has lower mechanical strengths overall. However, it is also impossible to overlook the advantages magnesium alloys have over aluminum. These include increased longevity, improved manufacturability, and quicker solidification because of reduced latent heat. As a result, castings have higher machinability and can be produced in greater quantities per unit of time than aluminum [18, 19].

Given that a vehicle's structural requirements are different, for instance stiffness and strength, it is essential to assess and determine finest matched magnesium composites for a specified constituent. Stability is just as significant as physical properties, mainly while assessing the duration of vehicles that are formed in big amounts. Even though magnesium possesses a suitable anti-corrosion properties, problematic galvanic pairs might inescapably be produced wherever further constituents join, reducing the whole car's durability. Consequently, the key attention is to examine effectual erosion avoidance methods, like metal alloy composition, covering, and separation procedures [34].

According to ground-breaking studies, weak textures (by altering the thermomechanical procedure) or through randomization by infrequent earth accompaniments may significantly enhance magnesium alloys formability of at room temperature [35, 36]. Nonetheless, in various magnesium alloy types, a reverse association between stretch formability and yield strength is noted [37], suggesting that relatively low strength could result from the increased formability. Additionally, if the industrial methods greatly depend on the adding of uncommon earth components, then the ending automotive elements will require a budget stretch.

TITANIUM

Apart from the substantial strength and small density (approximately 4.5 g/cm3), titanium and titanium alloys similarly exhibit superior resistance to corrosion, high ability to absorb energy, and high temperature performance [38]. Because certain magnesium and aluminum alloys miss sturdiness at elevated thermal conditions, alloys of titanium come to be a feasible alternative for motorized supplies that can meet ever-tougher weight-reduction and functional-improvement goals [39]. Figure 4 depicts the fuel tanks made from industrially pure titanium sheets (JIS Class 1) used in motorcycles launched by HONDA in 2017 and 2018.Titanium connecting rods replaced the conventional Steel shafts on the Honda NSX as well as Ferrari in the late 1990s, achieving a weight reduction of about 20% while simultaneously increasing strength [12]. The valve is another difficult part, but titanium alloys work well in lightweight automotive design, such as, Nissan Cima and Toyota ALTEZZA intake valves, that have high performance requirements at high temperatures (up to roughly 900 °C) [12, 40]. Common alloys of titanium has been categorized based on the Metallic components and pureness [41], such as low alloyed titanium (e.g., CP Ti, Ti-3Al-2.5 V, Ti-1Cu, and Ti-1.5Al) or commercially pure (CP), and alpha-titanium (e.g. Ti-1100 and Ti-6242S), alpha/beta (e.g., Ti-6Al-4 V, Ti-62S, and Ti-54 M, and beta-titanium (e.g., Ti-LCB). The cold formability of CP and low alloyed titanium makes them suitable for use on exhaust channels or silencers. Given their high strength, remarkable fatigue behaviors, and low modulus, β- alloys of titanium are therefore better suited for suspension coils and valves. Titanium suspension springs can reduce weight by 60–70% and free height by 50–80%, respectively, when compared to suspension springs made of traditional steel [42]. The use of titanium alloys in cars is still, in reality, restricted when compared to the aerospace and medical industries (mostly due to cost). At around $0.22 per pound, titanium's ore price is more than 20 times higher than aluminum's, which is about $0.01 per pound [43]. Although titanium alloys are extensively utilized in the automotive manufacturing, their great extraction as well as processing costs (the deciding factor) make them less attractive than other lightweight automotive materials or conventional materials.

Figure4. Design of a fuel tank constructed from JIS Class 1 industrially pure titanium sheet [39]

Polymers

Automotive uses already make extensive use of polymers, and lightweighting is only making this use more prevalent. In addition to being lightweight, plastics have excellent absorption qualities, which is advantageous from a safety standards standpoint. Special engineering plastics that can withstand high temperatures are necessary for internal combustion engine (ICE) vehicles; however, if the trend toward electrification of vehicles continues, their significance may decline. Rather, battery housing, sensors, car exterior, car interior, and other polymers will be used to make battery electric vehicles components. Additionally, polymers are becoming more significant in the form of reinforced plastics, also known as polymer matrix composites [44].

COMPOSITES

Modern composite technology offers significant benefits over conventional materials in the automotive sector. Composite resources are showing promise in a variety of applications these days. One such type of material is fiber-reinforced plastic composites, which are lighter and have many benefits for the motorized manufacturing for their light mass and potential for vehicle weight reduction. Because of their enhanced influence operation features, abilities to absorb energy, low-weight design, and corrosion resistance qualities [45], composites are a ideal alternative to metallic constructions for impact energy absorption in military and automotive applications. Outstanding erosion resistance and further chemical abilities can aid industrialists prolong the life of distinct parts and entire automobiles [46, 47].

Composites can reduce weight by 15–40% with different types of reinforcement. They also have other desirable qualities for the automotive manufacturing, for instance lower heat conductivity, higher specific strength, respectable erosion resistance, and design elasticity [48]. The motorized composite marketplace income in the United States has been steadily increasing over the past ten years. The most common matrix material is polymer composites, while ceramic and metal matrix composites come in second and third position, respectively.

Most polymer composites (roughly 65 percent) are utilized for the exterior and interior parts of cars, with the remaining portion going toward structural and powertrain systems, according to the global application pattern. Recent developments in nanotechnology also indicate that graphene-based nanocomposites, when used to construct panels, sensors, electronics, and interior components, have a great deal of promise for creating vehicles that are safer, lighter, more effective, and resilient. For instance, in 2016, Briggs Automotive Company created the first vehicle with graphene panels, and Ford used graphene supports to create stronger parts that were lighter and quieter [49].

Given its remarkable shaking, fatigue, and anti-corrosion property, high and precise strength/toughness, and remarkable safety performance, CFRP is arguably the most well-known option for lightweight design [50]. Outstandingly, CFRP is able to achieve 60 to 90 J/g of specific energy absorption (SEA), a crucial metric for automobile crash resistance styling [51].However, the SEA of conventional materials that absorb energy such as foams and aluminum honeycomb are only about 10 J/g. Carbon fiber components have advanced quickly in recent decades, but compared to the aviation and aerospace industries, the cost-conscious automotive sector still uses CFRP sparingly. Strong and rigid chassis [52] , ideal bumper beams [54, 55] , lightweight machine sub frames with outstanding mechanical action[55] , as well as reinforced top boards are some possible automotive uses for CFRP[56].

Natural fibers derived from animals or plants, for example, kenaf and flax are typically have less density than man-made fibers and offer a fair trade-off between cost per volume and tensile strength , which could serve as a substitute for artificial reinforcement in composites [57]. Natural fiber-reinforced composites offer excellent decomposability, non-lethality, and recoverability adding to price and weight decrease advantages, opening the door for the development of lighter, more environmentally friendly, and more cost-effective automobiles [58, 59]. Considering the exceptional ability of natural fiber composites to absorb sound, the increasing need for noise reduction can also be met [60]. Car parts like dashboards, seatbacks, and door panels have already made use of a variety of natural fiber-reinforced polymer composites [61, 62].

Prospects

The adoption of lightweight technology offers significant benefits to the electric vehicle sector. Soon, substantial growth in the use of lightweight resources for EVs is anticipated. Reducing automobile's weight by 10 percent could result in a 6 to 8 percent boost in power efficacy. Modern vehicles depend on lightweight materials for electric car batteries to enhance power efficiency without compromising safety. The growing focus on electrification and the need for fuel-efficient mobility are major drivers behind the automotive industry's rising demand for lightweight materials. The future of lightweight materials in the EV market looks bright, driven by the global transition towards electrification in the automotive industry.

CONCLUSION

For attaining sustainability in the motor vehicle manufacturing sector, it's vital to have high efficiency besides secure lightweight vehicles. The concept of lightweighting has evolved beyond merely replacing steel, moving towards mixed material approaches, combined with inventive strategy and multi-objective improvement. As more focus is being placed on rechargeable automobiles due to environmental concerns, lighter structural materials will play a crucial role in counterbalancing battery weight and boosting vehicle range.

Conflict of Interest

None

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