Proceedings of the 2023 International Conference on Mathematical Physics and Computational Simulation
DOI: 10.54254/2753-8818/28/20230474

A review of some new materials for lightweight and better performance purposes in vehicle components

Dong Wang[1, 5, 6, †], Zhihan Zhou[2, †], Zihan Liu[3, †], Chenghao Xue[4, †]

[1]School of advanced technology, Xi'an Jiaotong-Liverpool University, Suzhou, 215028, China
[2]Syracuse University, Syracuse, 13210, America
[3]Engineering department, University of Warwick, Coventry, CV47AL, United Kingdom
[4]Beijing National Day School, Beijing, 100039, China
[5]Corresponding author

[6]2444272964@qq.com
[7]zzhou68@syr.edu
[8]Zihan.Liu.4@warwick.ac.uk
[9]18210570558@163.com
[†]These authors contributed equally to this work and should be considered co-first authors.

Abstract. Automobiles are the world's primary way to travel, which leads to a constant race that automobile manufacturers are improving their vehicle performance by reducing weight. This paper introduces the values of density, yield strength, tensile strength, tensile modulus, flexural strength, and other properties of some new materials such as carbon fiber composite, magnesium alloy, aluminum alloy, high-strength steel, and carbon ceramic. Their drawbacks and advantages in vehicle industries and their potential development are presented in this paper.

Keywords: Lightweight, Automobile, Weight-Reduction, New Materials.

1. Introduction

In recent years, the vehicle industry has developed rapidly. At this stage, many vehicle manufacturers have gradually used many new materials in order to improve the overall performance of the car, such as new steel and iron, magnesium alloy, aluminum alloy, carbon fiber and glass fiber. Of course, they can also achieve lightweight development of the car while improving performance, which can not only improve the starting acceleration of the car, but also improve the overall performance of the car. And the reduction in fuel consumption leads to a reduction in carbon dioxide emissions. Therefore, the lightweight development of automobiles will be and will be the future development trend.

Carbon fiber is a remarkable material that has revolutionized numerous industries with its exceptional strength, lightweight nature, and versatility. Carbon fiber exhibits incredible mechanical properties that surpass those of traditional materials like steel or aluminum while weighing significantly less. This

DOI: 10.54254/2753-8818/28/20230474

unique combination makes it a sought-after choice in various applications, one of the most applications is on cars [1].

In the past, aluminum alloys were widely used on cars for several reasons, including low density, good conductivity, and excellent corrosion resistance. The low density is one of the most important reasons for adopting aluminum alloys. Compared to the density of steel, which is about 7.8 g/cm^3, surprisingly, the density of aluminum is almost three times smaller than that, which is 2.7 g/cm^3. It shows that substituting steel for aluminum will dramatically decrease the mass of the whole car. Cars of smaller mass can have better performance. It will be much easier for cars to make a turn, accelerate or decelerate [2].

However, magnesium alloy, as a new material, can be a better replacement for aluminum. In recent years so many countries have focused on and started further researching the application of magnesium alloy in lightweight automobile production because of the fuel economy and sustainable development. The density of Magnesium which is described as a kind of light metal is about 1.74 g/cm^3. Titanium and aluminum are also described as light metals, but their densities are 4.50 g/cm^3 and 2.77 g/cm^3, respectively. So, in terms of weight, magnesium is far superior to other metals in the production of lightweight vehicles. In addition, magnesium alloy has the characteristics of high specific stiffness, high specific strength seismic resistance, and noise reduction. So, magnesium alloy has been used in the industry of production of vehicles [3].

Applying lightweight material for the brake rotors can be quite efficient since reducing unsprung weight, which is the weight below a vehicle's suspension, can be more effective than removing the weight above the suspension. Traditional brake rotors are made of cast iron or steel, which has a density of about 7.1 g/cm^3. Carbon ceramic composite is a new material that has a density of 1.66 to 1.83 g/cm^3 and can be the material that replaces cast iron. Using carbon ceramic composite can save around 70% weight, assuming the size of the disc stays the same. Moreover, carbon ceramic composite has other advantages over cast iron in terms of material properties, such as better cooling efficiency and coefficient of friction. Saving unsprung weight can improve the power/weight ratio, enhancing the car's acceleration, deceleration, and turning performance.

This paper will discuss the mechanical and physical properties of carbon ceramic composite and compare them to cast iron, and decide which material will be better for the making of braking discs.

2. Discussion

2.1. Carbon fiber

Carbon fiber refers to high-strength and high-modulus fibers with a carbon content of more than 90%. In recent years, human research on carbon fiber is getting deeper and deeper and it has been used in aerospace, aviation, weapons, automobiles, high-performance sports, wind power, and other different industries because of its incredible characteristics and the development of new manufacturing techniques. Carbon fiber has good physical properties of high hardness, corrosion resistance, high toughness, stability, and lightweight. But it also has the barriers of high expense and the difficulty of perfect repairing. In this part, the application of carbon fiber in automobile manufacturing would be elaborated to reduce the weight of parts in vehicles.

The specific strength and specific modulus of carbon fiber composite materials are much higher than other metal materials, and its density is only 1.6, far less than the general metal materials, which provides a new idea for lightweight production, and the quality of the vehicle can be reduced by 35% by applying carbon fiber composite materials to the production of body and auto parts. The tensile strength of carbon fiber composite materials is generally above 3500Mpa, which is 5 times that of ordinary steel. Because the shape variable of carbon fiber is very small after the impact, this can ensure the safety of people to a certain extent when the car crashes, and because of the special weave structure of carbon fiber, it can also absorb a lot of energy during the collision to improve the passive safety of the vehicle. The weight of parts in vehicles can decrease by up to 55% which are made up of carbon fiber[4]. In specific, replacing wheels made of carbon fiber-reinforced composite materials with conventional materials can reduce the weight of the wheel by 40% to 50%. The reduction in wheel weight can not only minimize the steering force but also reduce the weight of the vehicle, thereby improving fuel efficiency and minimizing the impact of the vehicle on the environment. Thus it can be concluded that carbon fiber-reinforced polymer (CFRP) makes the optimal material for wheel manufacturing, it has a lighter mass with higher stiffness and strength, and because of the reduction in mass, thus reducing fuel consumption[5]. Bambach used a new technique to increase the strength-to-weight ratio of the carbon fiber roof structure by two times, this new technology is boding carbon fibers to the steel surface to strengthen the vehicle roof surface and reduce the weight, a 37-68% mass saving [6]. The reduction in carbon emission of 1g/km can be achieved by every 10 kg dropped off a vehicle. This not only improves fuel efficiency but also protects the natural environment[4]. Tables 1 and 2 all show the weight loss effect of carbon fiber.

Table 1. The weight of the car roof which is made up of two types of materials [7].

Description	Weight
Steel roof	11.2kg
Composite roof (CFRP)	5 to 5.5 kg
Weight reduction	6 to 6.6 kg

Table 2. The simulated and the tested weight of two kinds of bumpers and their intrusion and deflection [7].

	Weight (kg)	Intrusion (mm)	Deflection (mm)
Simulated	2.49	130	82
Tested	2.61	123	89
Conventional	3.9	136	93

The combined properties of carbon fiber are far superior to them. Currently, carbon fiber is widely used in some sports cars to attain lighter weight and higher accelerated speed. But the price of carbon fiber is higher than other materials such as steel, aluminum. The utilization of carbon fiber in family cars is limited and there are three reasons that cause the high price. Firstly, is that the Raw carbon fiber is more expensive. Secondly, the charring process requires precise control, and problems can easily occur during the process. Thirdly, the carbon fiber production process is complex, with high requirements, and low output. CFRP has been researched by the BMW Landshut Innovation and Technology Centre for over 10 years and the production of CFRP is increasing with the deepening of research [8].

2.2. Steel

Steel is an alloy made up with iron and certain percentage of carbon, along with small amounts of other elements such as manganese, silicon and phosphorus. Due to its excellent mechanical properties including high strength, durability, and low cost, steel can be shaped and processed in different ways to meet the specific requirements of automotive industry. Nowadays low-cost manufacturing and vehicle fuel economy become the objectives of automotive industry due to the increasing global competition and local legislation. Vehicle manufacturing company must balance the cost of material, production and energy consume during vehicle total life cycle. Although in many cases lightweight technologies may increase the cost of production due to the need of new processes and equipment, strict environment regulation and concerns of vehicle emissions force company reduce weight of vehicle and improve lightweight manufacturing. One of the main trends for producing lightweight automotive parts are the application of high strength steels. The following figure 1 shows the weight ratio of main components (excluding the powertrain) in a regular automobile.

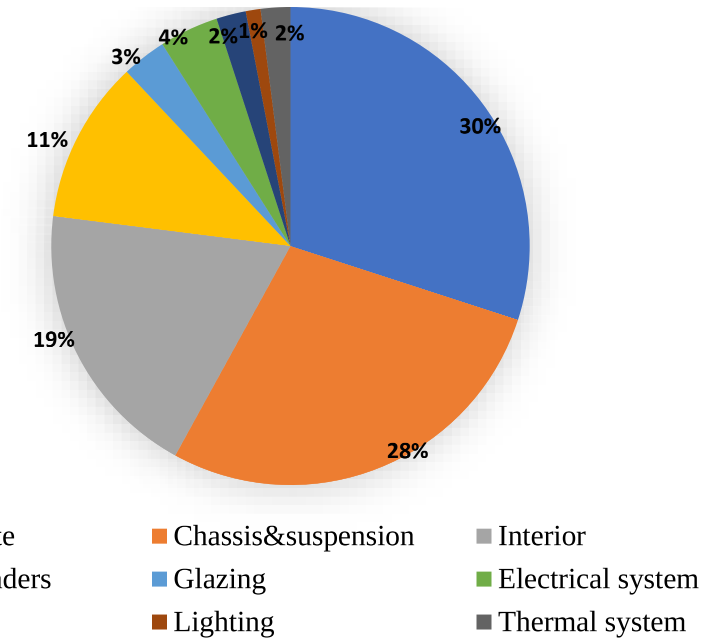

Figure 1. Weight contribution of main components in a regular vehicle.

In order to reduce weight, the automobile industry uses a variety of steel grades, including high-strength low-alloy (HSLA) steel, advanced high-strength steel (AHSS), and ultra-high-strength steel (UHSS). These steel grades provide increased ductility and strength, enabling the use of lighter and thinner components in the structure of the vehicle.

Along with these steel grades, (HSLA) grades of steel are frequently employed throughout the body structure, particularly for structural components that must have excellent spot weldability and support heavy loads. Because of their excellent formability, high strength, and affordable price, these steels are frequently utilized by the automotive industry. These steels are best used in parts like motor compartment rails, rocker side panels, and rear longitudinal rails. The yield strength, tensile strength, and overall percentage of elongation of 50 mm HSLA steel are displayed in the table 3 below [9].

Table 3. HSLA steel characteristic.

Grade designation	Yield strength (Mpa) minimum	Tensile strength (Mpa) minimum	Total elongation (%) Cold rolled	Total elongation (%) Hot rolled
300	300	400	27	27
400	340	410	25	25
380	380	450	23	23
420	420	490	18	22
550	550	620	16	18

In the table, HSLA steel has a yield strength of 300 MPa to 550 MPa, making it an excellent choice for applications that require a balance of strength and formability.

AHSS are characterized by their multiphase structures where ferrite is accompanied by other phases which have significant effect on the mechanical, forming and energy absorbing properties, by using precipitation hardening or solid solution strengthening. Specifically, by controlling the cooling rate from liquid to solid state, the amount of austenite transfer to martensite can be control so AHSS has better

DOI: 10.54254/2753-8818/28/20230474

yield strength and tensile strength. The following Table 4 shows the comparison between AHSS and HSLA metal.

Table 4. AHSS and HSLA steel comparison.

Grade designation	Yield strength (Mpa), minimum	Tensile strength (Mpa), minimum	%total elongation minimum, cold reduced	YS/TS ratio
DP600	340	590	21	0.58
DP800	420	780	14	0.54
DP1000	550	980	8	0.54
340HSLA	340	410	22	0.83
420HSLA	420	480	18	0.88
550HSLA	550	610	18	0.9

In contrast, a different variety of AHSS steel called "ferrite-bainite" steel has a stronger resistance to edge cracking than standard AHSS steels, making it ideal for applications involving flanged holes that must withstand severe loads and have high strength and heavy gauges. With a tensile strength of 580 MPa, the most popular grade of ferrite-bainite steel utilized in automotive applications nowadays is used almost entirely for control arms by some manufacturers. For a number of chassis parts, particularly suspension control arms, the introduction of ferrite-bainite steel with a 780 MPa tensile strength has proven to be an exceptional product. Some steel designs have even proven to be very mass competitive with the aluminum castings that predominate most current designs. Additionally, the economic advantages of steel designs over aluminum are particularly significant.

UHSS has a yield strength of 780 MPa to 1600 MPa, making it an excellent choice for applications that require the highest strength and energy absorption capabilities. one category of UHSS commonly used in automotive industry is multiphase steel. Structures requiring extremely high strength to prevent deformation are among the uses for high strength multiphase steels. For instance, low carbon and HSLA steels that previously predominated in the passenger compartment, rocker panels, and center pillar outer reinforcement can be substituted with UHSS. The usage of these steels has significantly increased the prospects for mass reduction and improved structural performance [10].

The following Table 5 shows details information of multiphase steels.

Table 5. Multiphase steels characteristic.

Grade designation	Yield strength (Mpa), minimum	Tensile strength (Mpa), minimum	Total elongation (%) minimum code reduced	YS/TS ratio
980/550Y	550	980	-8	0.56
980/650Y	650	980	-8	0.66
980/700Y	700	980	-8	0.71

2.3. *Aluminum alloy*

Aluminum alloy is a kind of alloy made of aluminum and other metal elements including copper, magnesium, silicon, nickel, and so on. We can find an aluminum alloy in either structural components or decorative components in a car for several reasons, including low density, good conductivity, excellent corrosion resistance, and so on. However, there are still reasons for the manufacturers to think twice about whether choose aluminum alloy or not. For instance, it is too expensive to be produced. The low density is one of the most important reasons why aluminum alloys are adopted. Compared to the density of steel which is about 7.8 g/cm^3, surprisingly, the density of aluminum is almost 3 times smaller than that, which is 2.7 g/cm^3. It shows that substituting steel for aluminum will dramatically decrease the mass of the whole car. Cars of smaller mass can have smaller inertia and lower fuel cost. It will be much easier for cars to make a turn, accelerate or decelerate. However, the demerits of aluminum alloys are also notable. For instance, it is too expensive to produce and hard to mend. Factories find it much more difficult to weld aluminum alloy than to weld steel. The price of a welding gun for steel ranges from ￥10,000 to ￥200,000, but the price of a welding gun for aluminum is about ￥800,000, which is a gigantic difference [11]. What's more, when a crash happens to an aluminum alloy part, it deforms and cannot be recovered to its original shape. The only way to fix it is to change a new part. There's another disadvantage, low melting point. The melting point of the most frequently used aluminum alloy, 6061, is only about 600 °C. This characteristic of aluminum alloys makes them unsuitable for use in high-temperature environments.

2.4. Magnesium

Since the twentieth century, the use of magnesium has soared. The majority of magnesium is used to make magnesium alloy. Magnesium alloy is a compound that combines other metal elements and the density of magnesium alloy is lower than 33% and 75% of the density of aluminum alloy and steel respectively [12]. Magnesium alloy is known as a green engineering material in the 21st century. From table 6, the characteristics of different magnesium alloys have a little difference. In general, however, magnesium alloys have the advantages of high specific strength and stiffness, high damping, electromagnetic shielding, good dimensional stability, thermal conductivity, excellent casting, machinability, and easy recycling. Easy corrosion, low ignition point, low creeping strength, low strength at high temperature, and low plasticity at room temperature are also drawbacks of magnesium alloy. According to the different kinds of metals in magnesium, magnesium can be divided into many series such as Mg-Mn, Mg-AL, Mg-Zn, Mg-RE. According to the different molding process, it can be divided into two main parts, deformed magnesium alloy and cast magnesium alloy [13]. From the moment, in addition to engineering applications, magnesium alloys are also widely used in the biological sciences due to their excellent biodegradability.

According to Liu at al [2]. The application of magnesium alloy in automobile parts manufacturing at different stages are introduced. From figure 2, the first stage is about 1808 to 1930. In this stage, people began to produce magnesium from metal oxide through the methods of chemistry and the first electrolytic Mg plant in Germany. 1939 to 1990s is the second stage. In this session, the engineering manufacturing of magnesium has been preliminarily developed and the racing concept cars and wheels made of magnesium appeared. The mass production of magnesium alloy happened in the third stage which is about 1992 to 2000. The last stage is from 2000 to now. The different components of vehicles are produced by magnesium alloy because of the production of lightweight vehicles and fuel economy, for example, engine, central control support, seat frame, backboard and wheel hub in pure electric cars and hybrid cars. The main magnesium alloy which can be used in production of vehicles are about Mg-Zn and Mg-Mn and Mg-Al. The table 1 shows the different application of different magnesium alloys [14]. With the development of further research on magnesium alloy, some problems can be solved by adding some specific metal elements to magnesium alloy. The addition of silicon to magnesium alloys can improve high-temperature creep strength in Mg–Al–Si–Mn systems. But if silicon is added to kinds of magnesium alloy which is low content of aluminum element, the whole castability will reduce. The castability and fluidity can be increased by adding rare earths elements [15]. Weiler and Wang [9] states that

AZ91D and AM60B have low thermal conductivity. This problem can be resolved by adding Ca and RE. through the study of adding different content of metal elements in magnesium alloy, most characteristic of magnesium alloy can be improved.

The cost of the magnesium alloy is higher than other metal alloys and there are also have some barriers in the process of production of magnesium alloy. Liu [12] explains these obstacles with reasonable reasons. On one hand, the price of magnesium is higher than other metals. On the other hand, the supply of magnesium is not sound. In conclusion, with the further research on magnesium and

DOI: 10.54254/2753-8818/28/20230474

development of the production process of magnesium alloy, the magnesium alloy will enlarge its advantages in the production of lightweight automobile.

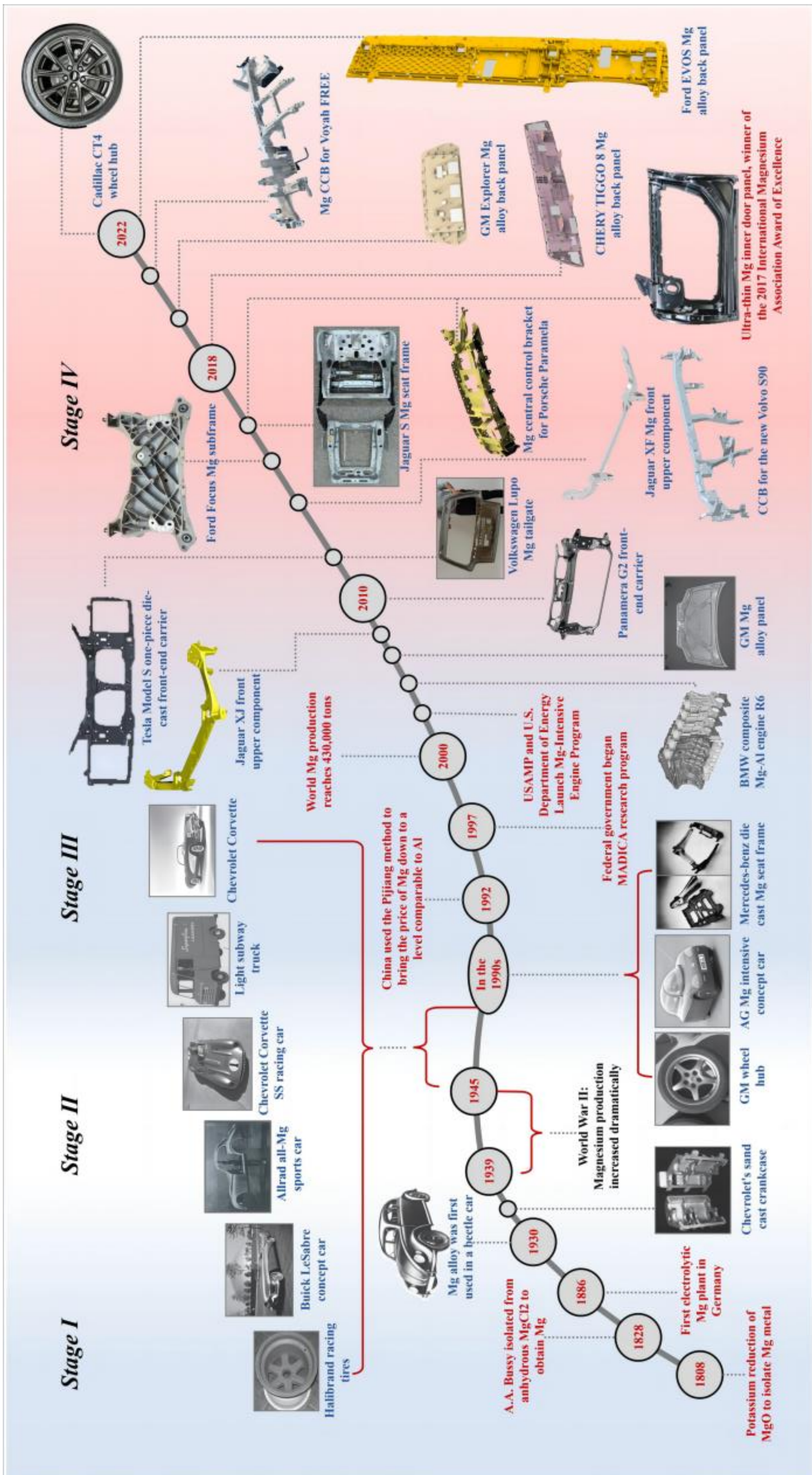

Figure 2. The history process of magnesium alloy in automobile industry [12].

DOI: 10.54254/2753-8818/28/20230474

Table 6. Different application of different magnesium [12].

Mg alloy series	Performance advantages	Specific classification	Application
AZ (Mg-AL-Zn-Mn)	Application to high strength, low ductility components in thermal environments below 125 degrees	AZ91D	Central control bracket, transmission housing, oil pan, oil filter housing, cylinder header cover, steering column bracket, inner panel, clutch housing, swivel plate, starter housing, headlight bracket
		AZ61	Luggage rack skeleton, column beam
		AZ31	Inner panel, compressor housing
AM (Mg-AL-Mn)	Used in thermal environments up to 125 degrees for lower strength, but more ductile components	AM60B	Front-end frame, cross car beam, seat frame, steering wheel, wheel/hub, radiator bracket, inside door panel
		AM50	Seat frame, wheel/hub, inside plate, steering wheel
AS (Mg-Al-Si-Mn)	Replaces AZ alloys at 125 degrees in the thermal environments due to increased creep strength	AS41B	Transmission housing crankcase housing

2.5. Carbon ceramic

Carbon ceramic composite is a new material that has a lower density than traditional materials such as cast iron and steel. It also has better cooling efficiency and high-temperature endurance. Carbon ceramic composite can endure a temperature of up to 1000 degrees Celsius, with great friction coefficients. The static friction coefficient is 0.68, and the dynamic friction coefficient is 0.32 [16]. Those properties make the carbon ceramic composite an excellent material for manufacturing brake discs.

The density of carbon ceramic composite is in the range of 1.66-1.83 g/cm^3 [16], which is over 70 % lower than traditional cast iron and steel. The material properties of the traditional steel brake discs materials are listed in table 7 [17]. The material properties of ceramics and composites are shown in table 8 [15], which is based on the methodology of the sandwich structure. The architecture of the sandwich structure is shown in Fig. 3 [18]. It has two face sheets on the outside, covering the core. Moreover, the core can have various forms, such as honeycomb, foam, folded, corrugated, and lattice & truss. This structure can significantly improve the stiffness and flexural strength while only increasing little amount of weight. The improvements in stiffness and flexural strength compared to the weight are shown in Fig. 4 [18]. The sandwich structure has many benefits, such as low overall density, good

DOI: 10.54254/2753-8818/28/20230474

thermal insulation, and uniform energy absorption capacity [18]. Although some of the advanced supercars have already equipped carbon ceramic brake systems, it is still a new material that can be applied to more sports cars. This reduces unsprung weight, which is more effective than reducing sprung weight.

Carbon ceramic composite is a better material than traditional cast iron and steel in all aspects in terms of use for brake discs. It can stop the car just as well as traditional brake materials. Also, its high thermal capacity and lightweight property make it a perfect role to replace traditional brake disc materials.

Table 7. Material properties of the traditional steel brake discs [16].

Temperature(°C)	Conductivity (W/(kg °C)))	Specific heat (J/(kg °C))	Young's modulus (Pa)	Expansion (/°C)
100	57	497	0.98×10^{11}	1.12×10^{-5}
200	74	525	0.88×10^{11}	1.20×10^{-5}
300	74	574	0.84×10^{11}	1.23×10^{-5}
400	74	634	0.71×10^{11}	1.27×10^{-5}
500	74	688	0.67×10^{11}	1.30×10^{-5}

Table 8. Material properties of some ceramics and composites [16].

Type	Name	Density (g/cm^3)	Melting temperature (K)	Service temperature (K)	Young's modulus (GPa)	Ultimate strength (MPa)	Sandwich components
Ceramics and composites	Nextel 720 composite	3.4	2073	1373	81 at 298K 46.6 at 1573K	1000-2000 at 298K 500-800 at 1600K	Facesheet
	C/C	1.60-1.98	>3925	2000	395 at 298K	98-235 at 298K	Facesheet
	SiC	3.21	>3000	1873	422 at 298K	240-1625 at 298K	Foam core
	C/Sic	1.7-2.1	>3000	1873	70-111 at 298K	198-312 at 298K	Facesheet and lattice, corrugated cores
	SiC/SiC	2.3-2.4	>3000	1873	220-420 at 298K	2000-2800 at 298K	Facesheet and corrugated core, lattice cores
	C/C-SiC	1.84	>3000	1873	50-70 at 298K	80-190 at 298K	Facesheet and honeycomb, corrugated, folded cores

DOI: 10.54254/2753-8818/28/20230474

Table 8. (continued).

	ZrO_2	5.60-5.89	2709	1273	240 at 298K	1600-2000	Facesheet and corrugated core
	ZrB_2-SiC-graphite	4.9-5.52	2273	2273	484-541 at 298K	245-1150	Facesheet and corrugated core

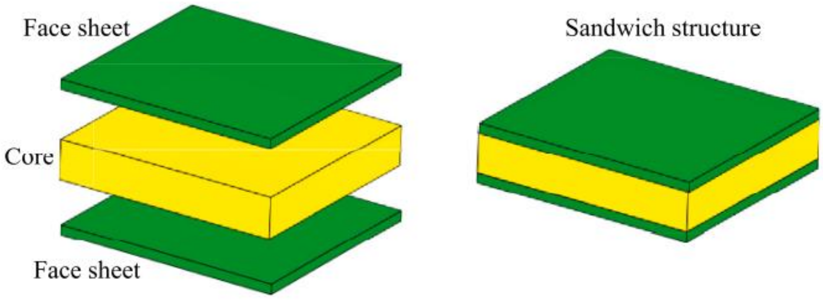

Figure 3. Sandwich structure [18].

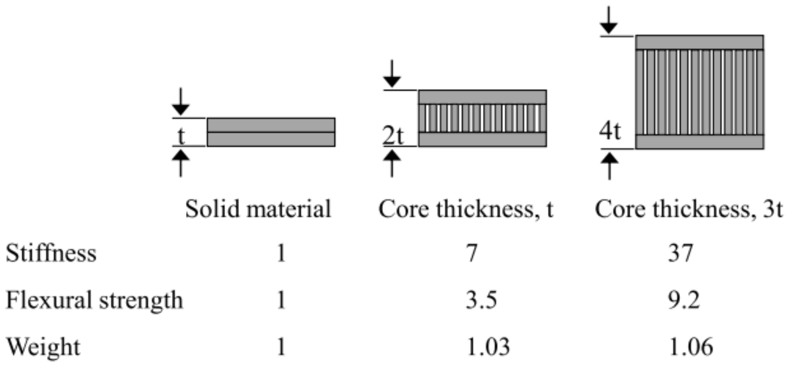

Figure 4. Stiffness and strength to weight ratio in sandwich structure [18].

3. Conclusion

To summarize

- The density, yield strength, tensile strength of carbon fiber are generally significantly better than other metals and their alloys, but it is basically used in sport cars because of the higher price, if the price can be reduced, carbon fiber will become popular in other kinds of vehicles.
- Steel application can be commonly found in automotive industry, by changing the percentage of carbon in steel, thinner and lighter components can be used in the structure of the vehicle while can also provide better structure performance
- While aluminum alloys offer advantages such as low density, good conductivity, and excellent corrosion resistance, their high production cost, difficulty in welding and mending, inability to recover from deformation, and low melting point make them less favorable for certain applications, particularly under high-temperature conditions.
- Magnesium alloys have low density and good toughness, but are still limited in the automotive manufacturing industry because of their active chemistry and comparative prices. With the development of science and technology and the investment of research, magnesium alloys will shine

- Carbon ceramic is an excellent material for manufacturing brake discs because of its low density, high cooling efficiency, high-temperature endurance, and favorable friction coefficients, making it a superior alternative to traditional materials.

New materials are enlarging its advantages in production of lightweight vehicles. But, the traditional materials like steels and aluminum alloys also have advanced in lightweight car manufacturing such as AHSS and UHSS. These advanced kinds of steels and some specific aluminum alloys also have their sets in vehicles production if the price of materials is considered. If the price is not considered when the vehicles are produced, magnesium alloys, carbon fiber compos and carbon ceramic are best choice because of the high price and light weight and the better performance. This paper mainly focuses on the properties of the material itself, ignoring the energy consumption in production and transportation. These factors should also be included if the material is to be evaluated. So the next step will be to further study the production of materials and the energy required to produce them.

Acknowledgement
Dong Wang, Zhihan Zhou, Andrew Liu, and Jason Xue contributed to this work and should be considered co-first authors.

References

[1] J. Zhang, G. Lin, U. Vaidya, and H. Wang, "Past, present and future prospective of global carbon fibre composite developments and applications," Composites Part B: Engineering, vol. 250, p. 110463, Feb. 2023, doi: 10.1016/j.compositesb.2022.110463.
[2] E. Corniani, M. Jech, F. Ditroi, T. Wopelka, and F. Franek, "TLA and wear quantification of an aluminium–silicon–copper alloy for the car industry," Wear, vol. 267, no. 5, pp. 828–832, Jun. 2009, doi: 10.1016/j.wear.2009.02.007.
[3] J. Rams, B. Torres, N. Pulido-González, and S. García-Rodriguez, "Magnesium Alloys: Fundamentals and Recent Advances," in Encyclopedia of Materials: Metals and Alloys, F. G. Caballero, Ed., Oxford: Elsevier, 2022, pp. 2–10. doi: 10.1016/B978-0-12-819726-4.00082-X.
[4] "Carbon fibre SMC halves weight of automotive parts," Reinforced Plastics, vol. 47, no. 7, p. 16, Jul. 2003, doi: 10.1016/S0034-3617(03)00715-X.
[5] E. Gardie, V. Paramasivam, H. Dubale, E. Tefera Chekol, and S. K. Selvaraj, "Numerical analysis of reinforced carbon fiber composite material for lightweight automotive wheel application," Materials Today: Proceedings, vol. 46, pp. 7369–7374, Jan. 2021, doi: 10.1016/j.matpr.2020.12.1047.
[6] M. R. Bambach, "Fibre composite strengthening of thin steel passenger vehicle roof structures," Thin-Walled Structures, vol. 74, pp. 1–11, Jan. 2014, doi: 10.1016/j.tws.2013.09.018.
[7] H. Ahmad, A. A. Markina, M. V. Porotnikov, and F. Ahmad, "A review of carbon fiber materials in automotive industry," IOP Conf. Ser.: Mater. Sci. Eng., vol. 971, no. 3, p. 032011, Nov. 2020, doi: 10.1088/1757-899X/971/3/032011.
[8] Jacob, "BMW counts on carbon fibre for its Megacity Vehicle," Reinforced Plastics, vol. 54, no. 5, pp. 38–41, Sep. 2010, doi: 10.1016/S0034-3617(10)70173-9.
[9] M. Tisza and I. Czinege, "Comparative study of the application of steels and aluminium in lightweight production of automotive parts," International Journal of Lightweight Materials and Manufacture, vol. 1, no. 4, pp. 229–238, Dec. 2018, doi: https://doi.org/10.1016/j.ijlmm.2018.09.001. (Accessed Mar. 01, 2023).
[10] C. D. Horvath, "Chapter 2 - Advanced steels for lightweight automotive structures," ScienceDirect, Jan. 01, 2021. https://www.sciencedirect.com/science/article/pii/B9780128187128000021#bib17 (Accessed Mar. 01, 2023).
[11] Y. F. Zheng, X. N. Gu, and F. Witte, "Biodegradable metals," Materials Science and Engineering: R: Reports, vol. 77, pp. 1–34, Mar. 2014, doi: 10.1016/j.mser.2014.01.001.

[12] G. G. Wang and J. P. Weiler, “Recent developments in high-pressure die-cast magnesium alloys for automotive and future applications,” Journal of Magnesium and Alloys, Oct. 2022, doi: 10.1016/j.jma.2022.10.001.
[13] R. Motallebi, Z. Savaedi, and H. Mirzadeh, “Post-processing heat treatment of lightweight magnesium alloys fabricated by additive manufacturing: a review,” Journal of Materials Research and Technology, vol. 20, pp. 1873–1892, Sep.2022, doi: 10.1016/j.jmrt.2022.07.154.
[14] B. Liu, J. Yang, X. Zhang, Q. Yang, J. Zhang, and X. Li, “Development and application of magnesium alloy parts for automotive OEMs: A review,” Journal of Magnesium and Alloys, Jan. 2023, doi: 10.1016/j.jma.2022.12.015.
[15] J. P. Weiler, “Exploring the concept of castability in magnesium die-casting alloys,” Journal of Magnesium and Alloys, vol. 9, no. 1, pp. 102–111, Jan. 2021, doi: 10.1016/j.jma.2020.05.008.
[16] L. M. Manocha, G. Prasad, and S. Manocha, “Synthesis and characterization of carbon–Silicon Carbide particulate composites by Powder Metallurgical Route,” International Journal of Applied Ceramic Technology, vol. 19, no. 1, pp. 119–129, 2021. DOI: 10.1111/ijac.13804.
[17] S. Zhang, J. Yin, Y. Liu, N. Liu, Z. Sha, Y. Wang, and B. Rolfe, “Thermal–structural coupling analysis of brake friction pair based on the displacement gradient circulation method,” Advances in Mechanical Engineering, vol. 10, no. 5, p. 168781401877381, 2018. DOI: 10.1177/1687814018773816.
[18] V. T. Le, N. S. Ha, and N. S. Goo, “Advanced sandwich structures for thermal protection systems in hypersonic vehicles: A Review,” Composites Part B: Engineering, vol. 226, p. 109301, 2021. DOI: 10.1016/j.compositesb.2021.109301.