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An assessment of new materials that are light weight for use in automobiles to improve fuel efficiency

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Abstract: Global energy demand is currently contributing to a severe problem of rising fuel prices for automobile users. One solution is to reduce the weight of the car body to improve fuel efficiency and reduce fuel costs. The choice of car body material can achieve this purpose. This paper will present the criteria such as stiffness, strength, and density to determine the suitability of substituting traditional materials, such as mild steel and carbon steel, with new materials High Strength Steel (HSS), aluminum alloys, and Long Fiber Thermoplastic (LFT). A literature review of the research is done to showcase the challenges traditional materials experience and how the development of these three new materials can overcome these challenges. Results from the case study show the feasibility of implementing these new materials in an automobile. More future research should be conducted to overcome the challenges and limitations posed by using these new materials, focusing on the low-cost replacement, manufacturing, and co-joining techniques of car body parts.

Keywords: new materials, High Strength Steel (HSS), aluminum alloys, Long Fiber Thermoplastic (LFT)

1. Introduction

Depleting non-renewable energy sources and demands for reducing emissions have triggered revolutionary evolutions in automobiles to improve fuel efficiency [1]. Concerning energy consumption, vehicles account for over 25% of gasoline use, and energy shortage may lead to severe consequences such as fuel cost inflation and environmental pollution. As automobiles are the second largest source of greenhouse gas emissions, rigorous environmental regulations in the unit of CO_2 emissions per kilometer have been enacted by governments to slash the emission to a great degree in the early future. For example, the United States plans to achieve average CO_2 emissions of less than 90 g/km by 2025, a reduction of about 40 percent from the figure recorded in 2015 [2]. Therefore, there is a demand to innovate a more fuel-efficient vehicle as the automobile industry affects energy issues extensively. Strategies have been proposed to address the rise of energy challenges, including vigorously pursuing the development of electric vehicles, enhancing drive train efficiency, and exploring lightweight materials. Among these, the most promising priority would be a weight reduction of vehicles by material

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selection. Besides energy consumption improvement and greenhouse gas emission control, weight reduction of vehicles via material selection could also contribute to superior recyclability and cost reduction for automakers [3]. Despite the excellence of traditional steel in strength, formability, and affordability, focuses have been shifted to the lightweight materials field, affecting the lightweight design of the vehicle. Lightweight materials can be classified into light alloys, High Strength Steel (HSS), composites, and advanced materials, as shown in Figure 1 [3]. These lightweight materials have been widely used as automotive components, as shown in Figure 2.

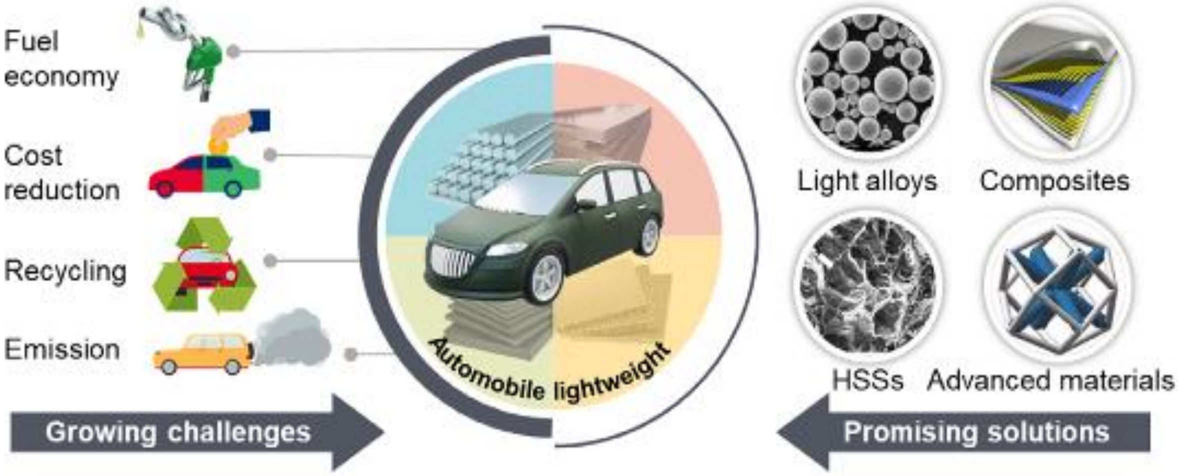

Figure 1. Automobile lightweight materials classification and contributions [2]

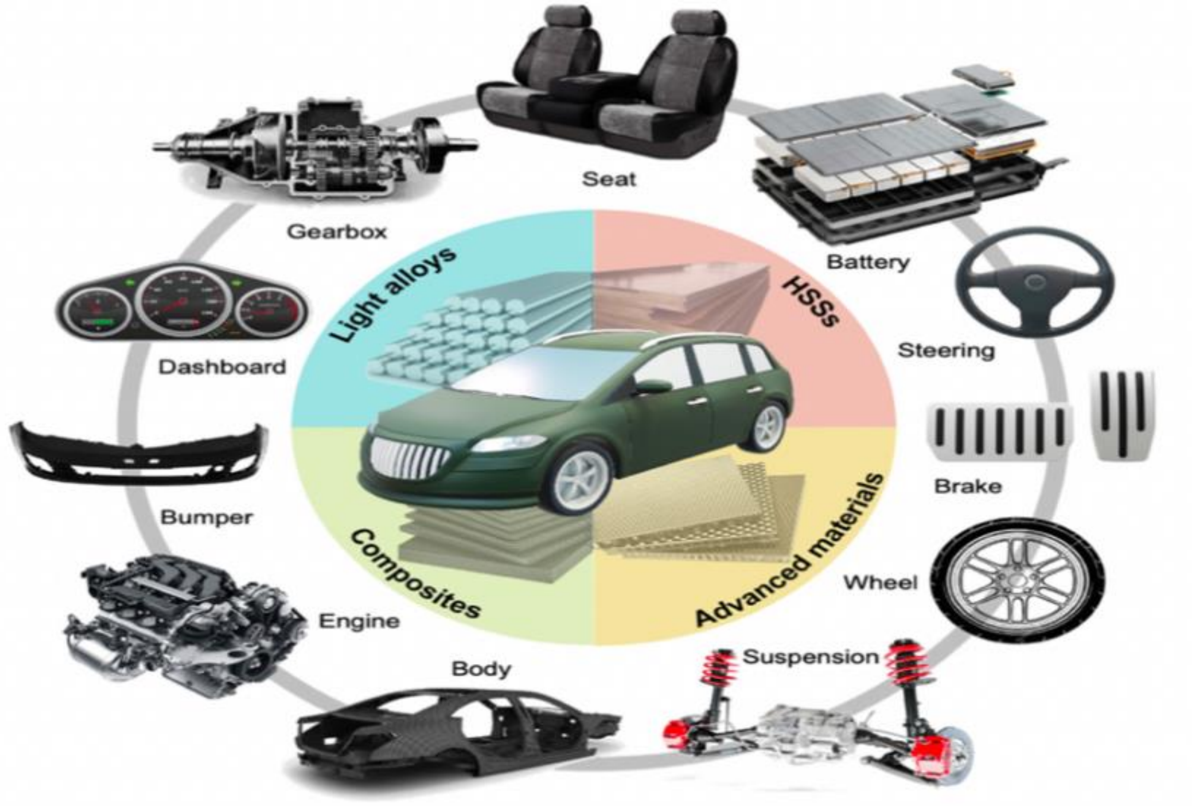

Figure 2. Various automotive applications with lightweight materials [2]

Previous research has already examined the implementation of the new lightweight materials. An article by A. Goel et al. revealed the reasons for the fatigue behavior of Long Fiber Thermoplastic (LFT), such as fiber orientation developed during processing and the hysteretic heating characteristic of the polymer matrix in response to cyclic loading [4]. A study by Yan Zhang et al. focused on proving the validity of

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using HSSs, instead of mild steel, as a lightweight material based on its crashworthiness [5]. Miklos Tisza and Imre Czinege compared and analyzed HSSs and lightweight aluminum alloys, which showed that when fuel savings benefit credit to lightweight aluminum lower density is considered, the overall vehicle manufacturing cost of aluminum Body-In-White (BIW) is enormously lower than that of a steel frame [6].

Due to the shortcomings of traditional low-carbon steels, HSS is used to replace them in the production of automobiles. Low carbon steel has some defects in impact absorption capacity and plastic deformation resistance of parts because these capabilities can be improved when HSS plates can be used in car bodies. Moreover, the low carbon steel plate of the body parts is hefty, and the low carbon steel plate of the body parts is replaced by the thinner high, strong steel plate, which can reduce the car's weight [7]. However, the structural performance of the traditional steel body is poor regarding yield strength. Ultra-light Steel Auto Body (ULSAB) has 19% lighter weight, high strength, and low manufacturing cost compared with the traditional steel body. Besides, although the cost of traditional steel is low, traditional steel provides greater thickness compared to HSS (yield strength between 210 and 550 MPa) and Ultra-High Strength Steel (UTSS) (yield strength over 550 MPa) [8].

Multiple studies have investigated the difference between new and traditional materials' applications in weight reduction to achieve fuel efficiency. This paper reviews the lightweight materials used in the automobile industry in terms of mechanical characteristics and comparison of both traditional and lightweight materials with more focus on representative materials such as LFTs, aluminum alloys, and HSS. As discussed, the problems and limitations posed by traditional materials have resulted in the growth of these new materials. First, the properties of various new materials are introduced, and specific comparisons between the new materials mentioned above and traditional materials such as low-carbon steel and mild steel will also be made. Next, case studies will be presented for applying each new material implemented in a real-world context. Subsequently, a thorough analysis of how the different materials used can help achieve fuel efficiency through weight reduction will be presented. Lastly, the limitations of our research will be highlighted before concluding and discussing the future steps.

2. Discussion

2.1 High Strength Steel (HSS)

2.1.1 Development of HSS

Steel is a popular choice for automobile production due to its low cost, high performance, excellent processability and recyclability, and ability to meet mass production requirements [9]. However, as mentioned, the automobile industry is shifting towards fuel efficiency to continuously weight-reducing and improving performance and safety. To overcome this challenge, scientists and researchers have been looking into areas to develop new types of steel with a high strength yet lightweight. An article by J. Schumitt reviewed the development process of HSS and Ultra High-Strength Steel(UHSS), which hinges on the development process of carbon steels that includes multiple hardening in different phases and quenching at average room temperature [10]. After several years of research and experimental trials, second and third generations of HSS are created. Finally, UHSS, which are steels with the highest yield strength (over 700 MPa), was developed [11].

2.1.2 The properties of HSS in comparison with traditional steel

It is known that HSS and UHSS are considerably light and have higher and similarly higher specific strength than traditional carbon steel and mild steel. As shown in Figure 3, traditional mild steels, such as mild and Interstitial-Free (IF) steels, are widely implemented in vehicle bodies due to their excellent formability and ultimate tensile strength (below 250 MPa). On the other hand, high-speed steels of conventional grades, for instance, Brake Hardened steel (BH) and High Strength Low Alloy steel (HSLA), are featured with high tensile strength, typically between 250 MPa and 700 MPa, but they both have low elongation [12]. As such, obtaining high strength and ductility simultaneously is difficult, as shown by the inverse relationship between the tensile strength-elongation of different steel grades.

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However, due to advancements in manufacturing technology in recent years, a new generation of UHSS has been created, which has both high strength and outstanding formability [12].

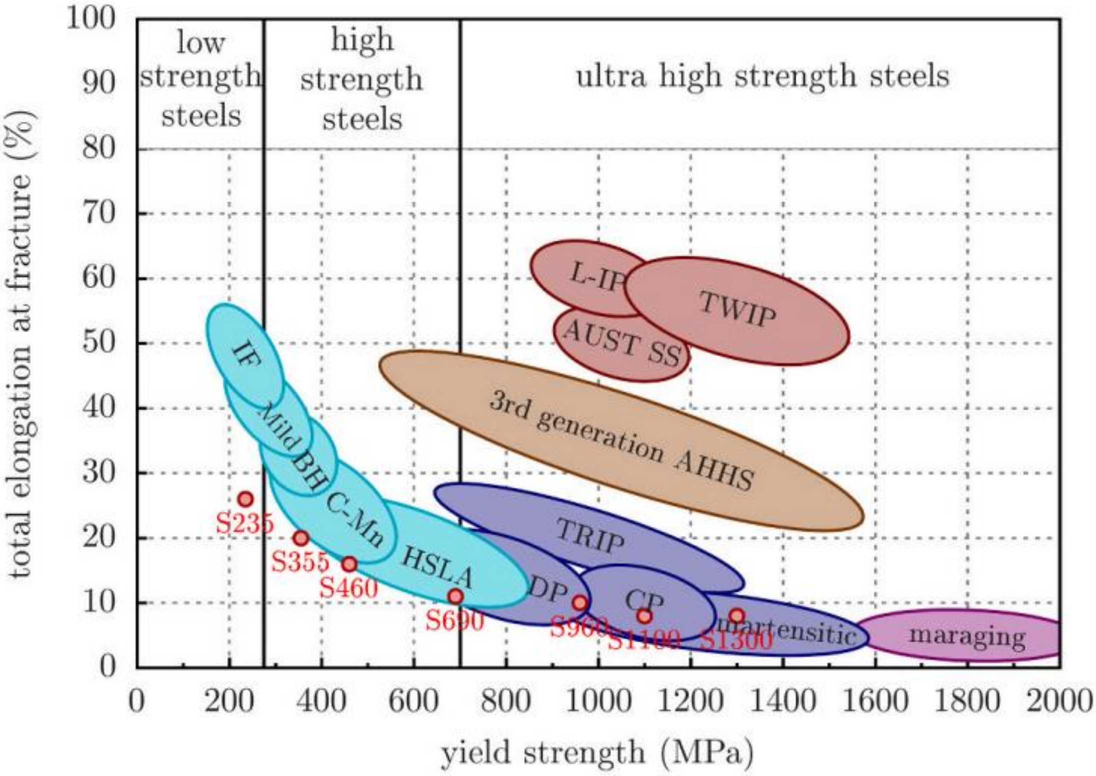

Figure 3. "Steel banana" plot showing all major steel groups as a function of nominal yield strength to total elongation at fracture with common structural steel grades included [11].

Additionally, HSS and UHSS must be able to maintain affordability while maintaining significant performance [13]. As a result, manufacturing similar functional parts in an automobile requires less HSS and UHSS material compared to mild steel, resulting in an overall weight reduction. Moreover, substituting mild steel with high-speed steel can significantly reduce the plate depth at the front of the body while having the same or greater impact absorbance. Advanced High Strength Steel (AHSS) Generations are listed in Table 1 [12]. The existing AHSS grades can be divided into first and second generation according to strength and elongation properties. In summary, the second generation AHSS has enhanced performance, such as more structural weight reduction and overall improvement in the strength and ductility than the first generation AHSS. Therefore, in the upper right area of Figure 3, more grades of high-precision AHSS may appear to make lighter, stronger, and more environmentally friendly automobiles.

Table 1. The first and second generations of AHSS' microstructures and strength ranges [12].

Generation	AHSS grades	Microstructures	Strength (MPa)
1st	Dual-phase (DP)	Ferrite + martensite	400–1000
	Complex phase (CP)	(Ferrite + bainite) matrix + small amounts of pearlite, martensite, and retained austenite	400–1000
	Martensitic (MS)	Martensite	700–1600
	Transformation-induced plasticity (TRIP)	Ferrite + martensite/ bainite + austenite	500–1000
2nd	Twinning-induced plasticity (TWIP)	Single-phase retained austenite	1100–1650
	Lightweight steel with induced plasticity (L-IP)	Single-phase retained austenite	850–1150
	austenitic stainless steel (AUST SS)	Single-phase retained austenite	900–1150

2.1.3 Case study

HSS, compared with traditional low-strength steels, exceeds in stiffness, strength, crashworthiness, and fatigue resistance. Hence, because of their ability to produce solid and ductile yet lightweight products, AHSS and UHSS have become the material of choice for components such as sill reinforcements, A and B-pillars, bumpers, and seats. For example, the 2016 Chevrolet Malibu employs AHSS to save 300 pounds over the 2015 model while allowing for a four-inch wheelbase increase. In addition, the 2016 Hyundai Tucson and the 2016 Kia Optima employ much more AHSS than the vehicles they replace, ensuring the new cars are lighter and stiffer. The 2016 Nissan Maxima has even lost 82 pounds using high-strength steels to increase torsional stiffness [14].

2.1.4 An analysis of the use of HSS

Steel has the advantages of low cost, good performance, and meeting the requirements of mass production. It is one of the essential materials in automobile production. The vehicle industry is constantly transitioning toward fuel efficiency to reduce weight while improving performance and safety. To address this issue, researchers have been looking at regions where new forms of steel with a high strength yet low weight can be developed. High-speed steels of standard grades, such as brake BH and HSLA, have high tensile strength but low elongation. The obtained second and third-generation HSS and ultra-high-speed steels have high strength and are superior to traditional low-strength steels in crashworthiness and fatigue resistance. They can reduce body weight, improve body performance and safety, and better fuel performance, thus protecting the environment. Compared to traditional mild steel, the new generation of ultra-high strength materials have better strength and formability and can make cars lighter and more environmentally friendly. These ultra-high-strength steels are widely used in car bumpers, seats, and other components. For example, they are replacing mild steel with high-speed steel can drastically lower plate depth at the front of the body while maintaining or improving impact absorption. By using these new materials as components, most cars save 300 to 400 pounds in price over

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their predecessors and lose about 80 pounds in weight [14].

2.2 Aluminium alloys

2.2.1 Development of aluminum alloys

The significant rise in fuel costs and potential environmental problems has led automobile industries to look for various alternatives for energy efficiency. One way to achieve this is to reduce the weight of automobiles while still ensuring their safety and improving their performance. Aluminium appears to be an excellent choice to replace the current traditional mild steel due to its low density (aluminum has a density of 2.7g/cm^3 while mild steel has a density of 7.8g/cm^3). However, challenges will arise if you merely replace traditional steel with aluminum alloys. It has a low tensile strength of 90MPa compared to traditional mild steel of 400MPa, which means replacing it may pose safety issues. In addition, the car may be threatened by fatigue and corrosion as pure aluminum generally possesses low tensile strength [15].

Scientists and researchers have been investigating the field of alloying elements to allow the alloy material to obtain better properties. For example, Copper and Zinc have excellent tensile strength, which can be combined with aluminum to produce lightweight and high-strength alloys [16]. Therefore, many studies have been done to investigate the ideal condition. For example, R.Rajan examined the range of suitable solubility of copper and zinc in aluminum and provided heat-treatment methods to create new types of aluminum alloy 7000 series [15].

Besides the aluminum 7000 series, which is famous for its high strength, different types of aluminum alloys are also developed (categorized into 1000 to 9000 series), and they can serve different purposes in the automobile industry. For example, 1000-series aluminum alloys can be used on heat insulators due to their excellent processability and corrosion resistance [17]. 2000 series aluminum alloys (with high copper composition) can be used in automotive pistons and connecting rods. 6000 and 7000 series aluminum alloys (with magnesium and silicon) can be used in Jacks, impact beams, and bumpers due to their high strength and good corrosion resistance. The development of aluminum has evolved such that the alloys are now used widely in place of various traditional materials in automobiles [15].

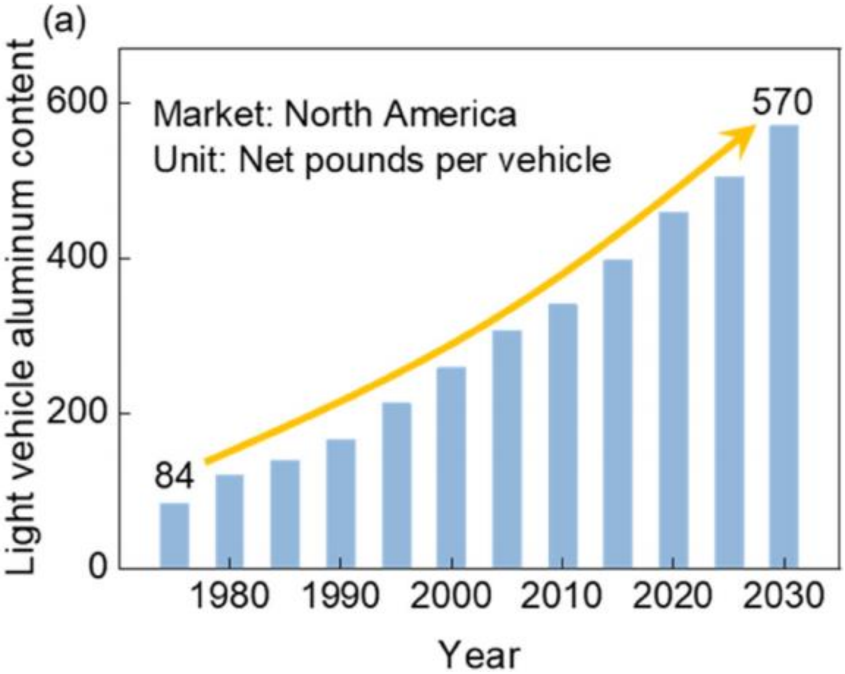

Figure 4. Usage of aluminum content in the light vehicle from 1975 to 2030 [15]

2.2.2 Properties of Aluminium 7000 Series Alloys in comparison with traditional steel

7000 series aluminum alloys were the focus of this paper analysis due to their comparable strength when placed alongside traditional materials. This series has an average high ultimate tensile strength of 444 MPa, while mild steel has 400MPa [18]. It can withstand high stress and fulfill its implementation requirements as a car body. Moreover, it has an average density of 2.72 - 2.89g/cm^3, which is approximately one-third of the density of traditional steel (7.75 - 8.05 gm/cm3). Therefore, substituting traditional materials with aluminum alloys can effectively reduce the car's weight while maintaining the standard of safety with its strength.

2.2.3 Case study

In modern society, the application of aluminum in automobile manufacturing is evolving trend. Even today, steel is the first choice for most carmakers. Meanwhile, some automakers are trying to reduce the weight of their vehicles due to customers' demands and new legal requirements on fuel consumption and environmental protection, s. From the perspective of automotive sheet metal forming processes, despite the growth of aluminum in automotive manufacturing over the years due to the application of castings for engine parts and forged parts for transmission components, the application of the Body-in-White (BIW) is the most promising area. However, recent research results show that the application of BIW can even achieve a 50% weight reduction effect, resulting in an overall weight loss rate of 30-40%. Moreover, significant development efforts have shifted to identifying suitable alloys for body panels and suspension components, though most of these have focused on relatively small amounts of alloys. Several groups of aluminum alloys have been applied in automobile manufacturing in recent years, including AA5754 H22 and AA6082 T6. For instance, AA5754 (AIMg3) alloy is used in sports cars widely and is of moderate strength compared to other aluminum alloys. AA6082 is a structural material used in many luxury cars, and this material is also suitable for aluminum body parts. [19].

2.2.4 An analysis of the use of aluminum alloy

As such, aluminum possesses mechanical properties which can satisfy an automotive's requirements while having a low density. Therefore, the need for lightweight has made aluminum a highly sought-after material. Due to its lightweight, this can ensure that the environment is impacted to a smaller extent as CO_2 emissions are reduced consequently. Substitution of aluminum alloys with steel in an automobile may save nearly 1 billion liters of fuel which, in turn, may transform into a 2-million-ton reduction in CO_2 emission [20]. Aluminum, therefore, serves as the secondary alternative to steel for this weight reduction which can improve fuel efficiency.

2.3 Long fiber thermoplastics

2.3.1 Properties of LFT in comparison with traditional steel

LFTs are the combinations of discontinuous fiber-reinforced polymer matrix composites (PMCs) and glass, carbon, or aramid fiber reinforcements with specific aspect (length versus diameter) ratios [21]. The material could bridge the gap between traditional fiber-reinforced compounds and composite with more accessible procedures under standard injection molding processing while maintaining better mechanical performance, cost, and excellent tailoring flexibility, as discussed below.

The typical processing method of LFTs could be classified into extrusion compression and fiber injection processes [22]. Furthermore, injection molding of the LFT parts could be divided into pultrusion compounding or compounding the glass fiber and other additives directly in-line with final part production (D-LFT). Moreover, the processing method adopted as well as the addition of material inclusive of matrix and fiber (e.g., level of addiction, actual sizes of fibers in the finished part, the aspect ratio) could affect factors below:

- porosity rate
- distributions of fiber length
- distributions of fiber orientation

Moreover, the specific parameters and applications in vehicles are shown in Figure 5.

Table 2. specific average parameters of LFTs

Material	***Density***	***Tensile Strength (MPa)***	***Tensile Modulus (GPa)***
LFTs	1.8	90	2

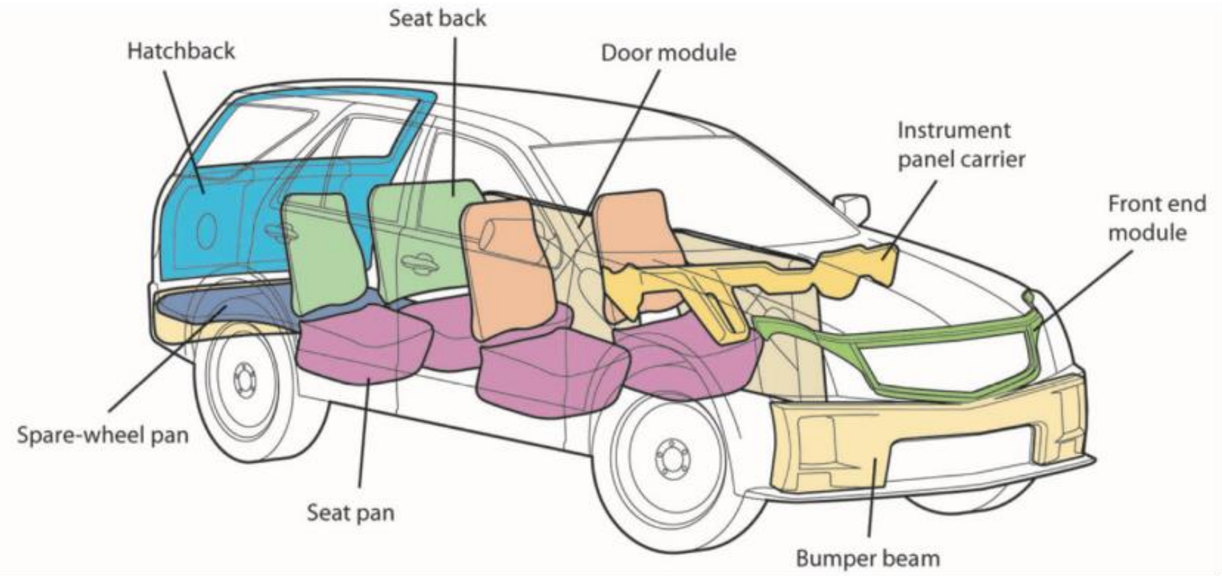

Figure 5. Pertinent application of LFTs in vehicles [23]

Below is a list of average values of traditional metals, thermoset materials and LFTs.

Table 2. Parameters for comparison between materials [21]

	Density	***Tensile Strength (MPa)***	***Yield Stress (MPa)***	***Tensile Modulus (GPa)***
Steel	7.8	300-1800	200-1700	210
Titanium	4.5	1000		105
Aluminum	2.8	75-700	30-550	75
Magnesium	1.75	85-255	43-190	44
SMC/BMC	1.5-2.0	50-350		21-51
LFT	1.8	90		2

As for mechanical performance, LFTs enjoy the advantage of stiffness and density over other traditional materials widely used in the automobile industry. Credit to their superior mechanical performance, they have replaced metal, short fiber reinforced thermoplastics, and thermoset plastics, including sheet molding compound (SMC) and bulking molding compound (BMC).

When compared with metallic material, LFT parts are lighter and corrosion-resistant. Apart from this, those stainless fibers could be widely used in electric components on a vehicle for shielding or static dissipation.

More metal parts are substituted as LFTs offer better structural stiffness and industrial-scale production capability. For instance, unidirectional tape combined with LFT could compete with existing metals and alloys in strength, which is feasible for strengthening connecting points. In addition, these LFTs have increased toughness, fatigue durability, and impact resistance than that thermoset material, and short-fiber formulations incorporate longer carbon, glass, and specialty fibers [23]. The high-temperature properties are also better with composites with longer fibers. As for cost, long fiber thermoplastics are typically processed via injection molding with faster manufacturing speed and lower consumption.

Moreover, engineering software could solve the challenge of fiber orientation control. Moreover, part consolidation of LFTs in the automobile industry is more economical when replacing metals with LFTs. The light LFTs could also prompt fuel efficiency during the life cycle of vehicles. Unlike other composites, injection molding could slash the price and simplify manufacturing.

Table 3. Comparison between SMC and LFTs [23]

	SMC	**GMT**	**LFT**
Matrix	Thermosets (e.g. UP-resin)	Thermoplastics (PP, PA, PET)	Thermoplastics (PP, PA, PET)
Reinforcement	Fibre mats	Glass fibre mats	Long glass fibres
Processing temperature	140–160 °C	25–80 °C	25–80 °C
Pressure	50–100 bar	100–300 bar	100–300 bar
Cycle time	1 minute	30–40 seconds	30–40 seconds
Specific properties	High-volume production ability Excellent part reproducibility	Not suitable for visible parts Good impact energy absorption	The high glass fiber content in deep ribs Low-pressure forces
Application	Car body in the automotive industry Oil pans	Bumper carrier Underfloor systems	Dashboard carriers Technical front-ends Bumper carrier, Underfloor systems

According to the table above, LFTs' processing time and environmental requirements are less demanding than SMC. For example, D-LFT or directly composite LFT does not require a pre-compounding step, which can significantly reduce energy consumption and the cost of polymer degradation and material handling [24].

2.3.2 Development of LFT

Considering the distinctions mentioned above, engineers are dedicated to innovating the product to meet versatile demands in the automotive fabricating industry. LFT becomes a perfect compromising technology between short fibers and advanced composites. However, the preliminary products consist of polymer pellets that are heated and converted into a composite melt using an extruder. Advanced converting from compression technology to injection is much more limited in geometries. Hence, the currently adopted method for fabricating advanced LFTs to solve the problem is injection instead of compression molding to provide design flexibility and cost savings by eliminating post-processing and adding functional elements. As the mechanical properties of LFTs vary a lot from traditional metal and another composite, the part design process is more difficult to cope with. PlastiComp is a pioneering materials company helping its clients with conceptual and development work, engineering, and computer analyses relative to LFTs [23]. The first step in designing a component of the LFT version is understanding the exact forces on specific positions of the part. After getting the proper fiber orientation in the areas of highest stress based on Computer Aided Engineering and Finite Element Analysis Flow, analyses would be conducted to check the fiber alignment in part and additional changes based on weld lines. The design problem would be solved fast and inexpensively with credit to Computer-Aided Design after iterations. Nonetheless, coloring LFT is a problem that needs to be solved, as fiber breakage and the weakened coupling chemistry between the resin and fiber would be caused by pigments. Process processors and engineers are continuously searching for methods of improving gloss by taking factors such as residence time, shear levels, and color addition points.

2.3.3 Case study

LFT has been applied in structural and semi-structural applications in the automotive industries. For example, front-end modules, bumper frames, instrument panel frames, battery trays, spare tire compartments, seat frames, foot pedals, and integral bottom plates. Apart from these structural and semi-structural components, LFT is also used to produce car hooks, dashboard skeletons, and battery trays. As LFT has a very high hardness and lightweight, its thermal expansion coefficient is almost identical to metal. As a result, its outstanding performance in light-weighting and its high strength make LFT a great choice to be used for manufacturing. Please take the 2003 Volkswagen Golf V front-end framework as an example, it is produced by D-LFT.

2.3.4 An analysis of the use of LFT

To conclude, LFT is an excellent choice for producing some components in the automotive industry and is continuing to show strong growth as they replace metal. As LFT materials have long glass fibers and are much lighter than metals, they have enough strength and can contribute a lot while reducing the weight of the vehicles. LFT materials offer engineers a large amount of design flexibility. It has also been applied in structural and semi-structural applications and has succeeded greatly. However, worker fatigue may be the main shortcoming of the materials. If the problems can be solved, LFT will be more widely used in the automobile industry.

3. Conclusion

Detailed analysis of the three new materials HSS, aluminum alloys, and LFT, and a comparison of their mechanical properties with traditional materials, such as mild steel and carbon steel, were made. All three new materials have values of Young's Modulus above 207 GPA, density below 7.75g/cm^3, and tensile strength above 300Mpa, which fulfill the safety requirement of being used on an automobile while reducing the weight effectively. Results show that these new materials can be excellent substitutes for traditional materials in automobile manufacturing. They can overcome the challenges experienced when using the current traditional materials and successfully achieve the objective of fuel efficiency. Therefore, this may reduce carbon emissions and potentially help save the environment while alleviating the problems of climate change.

3.1 Limitation

Firstly, the paper only discusses replacing only three materials which may not represent all new materials. Other mechanical properties beyond physical strength may influence the application of a material in an automobile that was not accounted for in this paper. Next, another limitation to be considered is the costs of manufacturing and replacing steel with lighter materials. Finally, the paper only discusses the suitability of substituting traditional material with new material in the automobile by comparing numerical values without the consideration of other factors which may affect the designing and assembly stages.

3.2 Future steps

In order to be able to use new alternative materials such as aluminum alloy, more studies should be done in the areas of cost-effective replacement, manufacturing, and co-joining techniques of car body parts. More studies should be done to investigate the application of different new materials in automobiles beyond HSS, LFT and aluminum alloys.

References

[1] K. K. Dama, V. S. Babu & R.N. Rao, “State of the Art on Automotive Lightweight Body-in-White Design,” Materials Today: Proceedings, vol. 5, pp. 20966-20971, Oct. 2018.

[2] W. Zhang, J. Xu, “Advanced lightweight materials for Automobiles: A review,” Materials & Design, vol.221, Apr. 2022.

[3] Kelly, Jarod C., John L. Sullivan, Andrew B., and Amgad E., "Impacts of vehicle weight reduction via material substitution on life-cycle greenhouse gas emissions." Environmental science & technology 49, no. 20:12535-12542, 2015.

[4] A. Goel, K. K. Chawla, U. K. Vaidya, N. Chawla, and M. Koopman, “Characterization of fatigue behavior of Long Fiber Reinforced Thermoplastic (LFT) composites,” Materials Characterization, vol. 60, no. 6, pp. 537–544, Dec. 2008, doi: 10.1016/j.matchar.2008.12.020.

[5] Y. Zhang, X. Lai, P. Zhu, and W. Wang, “Lightweight design of automobile component using high strength steel based on Dent Resistance,” Materials & Design, vol. 27, pp. 64–68, Sep. 2004, doi:10.1016/j.matdes.2004.09.010.

[6] 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, Sep. 2018, doi: 10.1016/j.ijlmm.2018.09.001.
[7] Yan Zhang, Xinmin Lai, Ping Zhu, Wurong Wang, “Lightweight design of automobile component using high strength steel based on dent resistance,” Materials and Design, vol. 27, pp. 64-68, September. 2004.
[8] Manoj Kumar Gupta, V. Singhal, “Review on materials for making lightweight vehicles,” Materials Today: Proceedings, vol. 56, pp. 868-872, March. 2022.
[9] Singh, Mayank Kumar. "Application of steel in automotive industry." International Journal of Emerging Technology and Advanced Engineering 6, no. 7, pp. 246-253, 2016.
[10] Schmitt, Jean-Hubert, and Thierry I. "New developments of advanced high-strength steels for automotive applications." Comptes Rendus Physique 19, no. 8, pp. 641-656, 2018.
[11] M. Tümer, C. Schneider-Broskamp, N. Enzinger, “Fusion welding of ultra-high strength structural steels – A review,” Journal of Manufacturing Processes, vol. 82, pp. 203-229, August. 2022.
[12] M.Y. Demeri, "Advanced high-strength steels: science, technology, and applications," ASM international, 2013.
[13] Yuxuan Li, Zhongqin Lin, Aiqin Jiang, Guanlong Chen, “Use of high strength steel sheet for lightweight and crashworthy car body,” Materials and Design, vol. 24, pp. 177-182, January. 2003.
[14] Anderton, James. “Aluminum versus Steel: Ferrous Fights Back with AHSS.” Engineering.com, 24 Aug. 2015, https://www.engineering.com/story/aluminum-versus-steel-ferrous-fights-back-with-ahss. (accessed on Sept. 2, 2022)
[15] Rajan, R., Kah, P., Mvola, B.Martikainen and J. "Trends in Aluminium Alloy Development and Their Joining Methods." Reviews on Advanced Materials Science 44, no. 4, 2016.
[16] Igelegbai, Edward E., et al. "Evaluation of mechanical and microstructural properties of α-brass alloy produced from scrap copper and zinc metal through sand casting process." Journal of Minerals and Materials Characterization and Engineering 5.1, pp.18-28, 2016
[17] Zhang, Wen, and Jun X. "Advanced Lightweight Materials for Automobiles: A review." Materials & Design 221: 110994, July 2022.
[18] Overview of materials for 7000 Series Aluminum Alloy, https://www.matweb.com/search/DataSheet.aspx?MatGUID=ab9706916818406b80c22b7f39db0c78 (accessed Sept. 10, 2022)
[19] Miklos Tisza, Imre Czinege, “Comparative study of the application of steels and aluminium in lightweight production of automotive parts,” International Journal of Light Materials and Manufacturing, September. 2018, doi: 10.1016/j.ijlmm.2018.09.001.
[20] Ferreira, Victor, Pedro E., Vladimir P., Maider G., Ane I., Ana M., and German F. "Lightweight automotive components based on nanodiamond-reinforced aluminium alloy: a technical and environmental evaluation." Diamond and Related Materials, Vol.92, pp174-186, 2019.
[21] M. Biron, “Thermoplastic Composites,” Thermoplastics and Thermoplastic Composites, pp. 821-882, July. 2018.
[22] S. Alwekar et al, “Melt extruded versus extrusion compression molded glass-polypropylene long fiber thermoplastic composites,” Composites Part A: Applied Science and Manufacturing, vol. 144, February. 2021.
[23] J.Markarian, “Long fibre reinforced thermoplastics continue growth in automotive,” Plastics, Additives and Compounding, vol. 9, pp. 20-24, March–April. 2007.
[24] D. Mathijsen, “Long fiber thermoplastics are a key technology in expanding existing markets for composites,” Reinforced Plastics, vol. 63, pp. 267-272, December. 2019