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Review Paper

Trends in Lightweight Automotive Materials for Improving Fuel Efficiency and Reducing Carbon Emissions

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Abstract
Depletion of fossil fuels and greenhouse gases is an essential issue in the development of the automotive industry. From the design stage, material selection becomes the most crucial factor. Therefore, this article discusses the development of lightweight automotive materials for increasing fuel efficiency and reducing carbon emissions. Material reliability is assessed by how much weight reduction can be achieved, production costs, safety and durability. Ferro materials (mild steel, High Strength Steel, and Advanced High-Strength Steel, non-ferrous (aluminium and magnesium alloy), and Fiber Reinforced Plastics (FRP) have been proven to reduce the total weight of vehicles up to 12.6%. Confirmation of statistical data from the literature illustrates the possibility of using lightweight material to achieve zero CO₂ emission. In addition, the 12.6% weight reduction still meets the vehicle safety factor.
Key words: Lightweight material, AHSS, FRP, Emission reduction

Abstrak
Penipisan bahan bakar fosil dan gas rumah kaca adalah menjadi isu penting dalam perkembangan industri otomotif. Dari tahap desain, pemilihan material menjadi faktor terpenting dan yang pertama kali dipertimbangkan. Oleh karena itu, artikel ini membahas perkembangan material otomotif bobot ringan untuk peningkatan efisiensi bahan bakar dan pengurangan emisi karbon. Keandalan material dinilai dari seberapa besar pengurangan berat yang dapat dicapai, biaya produksi, tingkat keselamatan dan ketahanan. Material ferro (mild steel, High Strength Steel, dan Advanced High-Strength Steel) non-ferro (paduan aluminium dan magnesium), dan Fiber Reinforced Plastics (FRP) terbukti dapat mengurangi berat total kendaraan hingga 12,6%. Konfirmasi pada data statistik dari literatur, memberi gambaran kemungkinan penggunaan material bobot ringan dapat mencapai zero CO₂ emission. Selain itu, pengurangan berat 12,6% masih memenuhi faktor keamanan kendaraan.
Kata Kunci: Material bobot ringan, AHSS, FRP, Pengurangan emisi

1. Introduction
According to the results of a review by British Petroleum 2018, world oil production in 2017 reached 92.6 million barrels per day (MMbbl/d) of which, the Asia Pacific contributed 8.5%. Asia is the largest energy consumer for oil, coal, renewable energy and electricity based on hydropower. Meanwhile, Indonesia's fuel

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Abstrak

Penipisan bahan bakar fosil dan gas rumah kaca adalah menjadi isu penting dalam perkembangan industri otomotif. Dari tahap disain, pemilihan material menjadi faktor terpenting dan yang pertama kali dipertimbangkan. Oleh karena itu, artikel ini membahas perkembangan material otomotif bobot ringan untuk peningkatan efisiensi bahan bakar dan pengurangan emisi karbon. Keandalan material dinilai dari seberapa besar pengurangan berat yang dapat dicapai, biaya produksi, tingkat keselamatan dan ketahanan. Material ferro (mild steel, High Strength Steel, dan Advanced High Strength Steel), non-ferro (paduan aluminium dan magnesium), dan Fiber Reinforce Plastics (FRP) terbukti dapat mengurangi berat total kendaraan hingga 12,6%. Konfirmasi pada data statistik dari literatur, memberi gambaran kemungkinan penggunaan material bobot ringan dapat mencapai zero CO₂ emission. Selain itu, pengurangan berat 12,6% masih memenuhi faktor keamanan kendaraan.

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consumption in 2017, according to the results of this review is above the UK and France, which is 1.6 MMbbl/d [1]. However, according to Davis [2], in 2010, the United States consumed fuel above 19 MMbbl/d, and its production was only 7.51 MMbbl/d. This deficit is filled with imports and will cease due to limited sources of crude oil.

Efforts to improve fuel efficiency in the automotive sector are essential to ensure sustainability [3]–[7]. Also, the automotive industry has an environmental responsibility from the effects of large fuel consumption, namely greenhouse gas emissions, especially carbon emissions from combustion. Reducing fuel consumption and carbon emissions solutions will not work without strong support from efficient vehicle technology, one of them is through the engineering of lightweight materials [8].

Increasing fuel prices have changed the paradigm of automotive consumers to choose fuel-efficient vehicles. Automotive manufacturers have also responded to this consumer behaviour by increasing fuel efficiency and reducing vehicle weight. Lightweight vehicles are the most reasonable solution because there is an inherent relationship between vehicle mass and fuel consumption [8]. The results of studies by the Massachusetts Institute of Technology states that 35% reduction in vehicle weight is still acceptable and can save fuel consumption between 10-20% [9]. Similarly, according to the results of previous research, lighter vehicles will be more efficient because 70% of fuel consumption is used by vehicle weight [10].

From the design stage, material selection becomes the most critical factor, and it is the first to be considered. At least the requirements for lightweight, economical, safe and recyclable materials must be included in automotive design [11]–[13]. There are four major groups of materials for automotive: metals, plastics, composites and ceramics. Metals used in automotive include steel, cast iron, sintered metals, aluminum alloys, magnesium alloys and metal-based coatings. Polypropylene, Polyurethane, and PVC, represent plastics. Composite with a polymer matrix or glass fiber reinforced metal, carbon fiber is also

used. Ceramics are used for coating materials and components. Figure 1 shows the composition ratio of the automotive part (excluding the power successor component), which is 77% used for the frame/body in white, chassis and suspension. This composition makes the focus of material research today leading to the use of lightweight materials (non-Ferro and composites) for lightweight automotive to answer the challenges of fossil fuel consumption and the reduction of greenhouse gas effects.

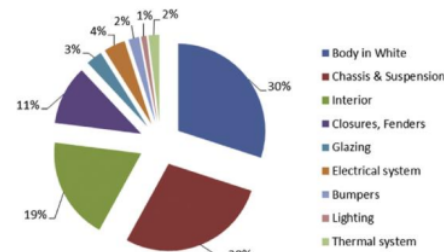


Figure 1. Automotive component weight ratio [14].

Therefore, this article provides a discussion of the literature related to the development of material that is being developed or has been used to produce light weight vehicles to increase fuel efficiency. The study of ferrous, non-ferrous, and polymeric composite metal materials is reviewed from the contribution to reducing vehicle weight to achieve the goal of fuel efficiency and carbon emission reduction.

2. Ferro Materials

2.1. Carbon steel and cast iron

According to the international organisation of vehicle manufacturer (OICA), 95.6 million vehicles were produced in 2018 [15]. Of the average weight of 900 kg vehicles, 69% of the material is ferrous metal. In details, 34% in structural components, 23% in propulsion systems, and 12% in suspensions. Krauss [16], stated that Ferro material is a considerable alloy group based on the element iron (Fe) with the primary alloy being carbon (C) and the addition of one or more other alloying elements. Based on the literature, the Fe-Fe₃C phase diagram (Figure 2) of the most basic categories of ferrous materials is carbon steel and cast iron.

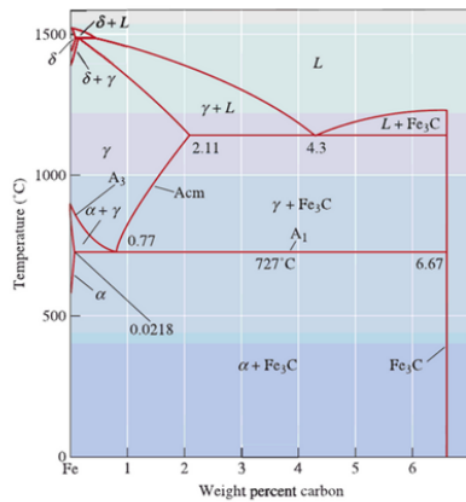


Figure 2. Fe-Fe₃C phase diagram with horizontal lines is 6.67% C composition, which is a stoichiometric composition for Fe₃C compounds [17].

From Figure 2, we can show the difference between the two primary engineering materials, carbon steel and cast iron. Carbon steel has a carbon composition range between 0.0218 - 2.11%, while in cast iron between 2.11 - 6.67%. Carbon steel has excellent properties for automotive purposes such as shape, ductility, strength and toughness. When exposed to an impact load, carbon steel is not necessarily destroyed but is deformed. These properties are needed for vehicle safety considerations. The carbon steel also has stainless properties that are good enough for vehicle applications. A property that is considered to be a weakness of carbon steel related to the contribution of reducing vehicle weight is its density of 7.85 kg/m³. However, carbon steel has the advantage of being able to reuse through remelting/re-smelting and welding capabilities so

that it is considered economical for industrial scale.

Another ferro material that is still used for automotive components is Austempered Ductile Iron (ADI). ADI is cast iron that is processed through casting with strict composition control, followed by austempering heat treatment process that is well controlled [18]. Figure 3 shows the austempering process and the pair of ADI-based hypoid gear and ring gear.

The heat treatment process in Figure 3a shows the austempering process cycle. The casting metal is heated to austenite temperature at 900 °C followed by detention for a particular time, then cooled to 400 °C. The metal is held at 400 °C for several hours to transform isothermally. After cooling in the air, the microstructure of bainite is obtained, which is carbide-reinforced acicular ferrite. The bainite property exists between soft ferrite and martensite, which is hard but tends to be brittle. The results of the combination of these microstructures, provide material with toughness, tenacity, and excellent strength. In this case, the optimum performance of gear is needed.

Figure 4 shows the ADI microstructure consisting of bainite with free carbon or spherical graphite with variations in mechanical properties based on the austempering temperature function. For automotive applications, ADI offers three advantages; 1) high weight-strength ratio (strong but light), 2) low cost-strength ratio (cheap but strong), and 3) 100% recyclable [19]. ADI material with a thickness of 3 mm can compete with cast aluminium (sand casting/sand casting or die casting). Likewise, this ADI product can compete with steel stamping followed by normalising as well as heat treatment, forging, and casting.

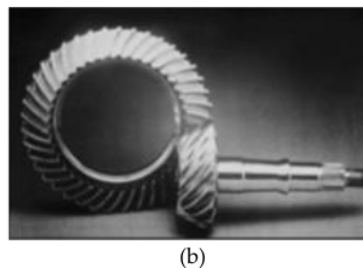
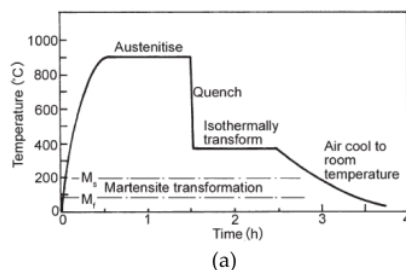


Figure 3. Austempering process (a) and the pair of ADI-based hypoid gear and ring gear (b) [18]

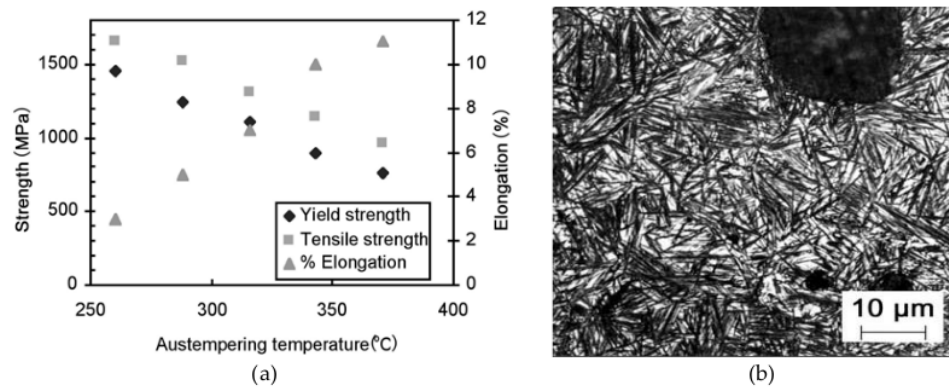


Figure 4. Mechanical properties as a function of austempering temperatures (a) and microstructures of bainite (acicular ferrite + carbide) with free carbon in ADI material (b) [18].

2.2. Advance High Strength Steel (AHSS)

AHSS is steel with a tensile strength of ≥ 500 MP, with a microstructure consisting of ferrite, martensite, bainite, and retain austenite [20]. AHSS is made by hot working in the single austenite phase and cold working areas in the austenite-ferrite dual-phase region through control of the chemical composition and cooling rate (see Figure 2). The AHSS category follows the resulting microstructure (DP/dual-phase, TRIP/transformation induced plasticity, CP/complex phase, MS/martensite, FB/ferritic bainitic, TWIP/twinning induced plasticity, HF/hot formed, and PFHT/post-forming- heat-treatable). Then, the AHSS nomenclature follows the following syntax: typeAHSS_min.yield strength/min.ultimate strength. Example: DP 500/800 means Dual-Phase steel with a minimum yield strength of 500 MPa and a minimum tensile strength of 800 MPa [21].

Some AHSS have high strain hardening capacity due to excellent strength-ductility support. With AHSS, car manufacturers can reduce vehicle weight by 25-39%. If the total weight of the vehicle is reduced from 170 to 270 kg, then during the lifetime of the vehicle a greenhouse gas emissions savings of 3 to 4.5 tons are obtained. That is, fuel savings over the life of this vehicle are able to neutralize the effects of CO₂ emissions that arise when all components of the vehicle are produced [22]. Meanwhile, in Figure 5,

Schultz gives an estimate of the increase in AHSS in automotive until 2020 only to 157 kg (346 lb).

Steel, based on its function in automotive, is divided into two big groups, AHSS and HSS. AHSS with high strength and toughness for structural applications that absorb energy and anti-intrusion is categorized as BIW / body-in-white, namely a series of vehicle frames without doors, roofs, declids and fenders. HSS with good shape and surface quality, as well as scratch resistance, for external appearance applications related to painting, categorized as closing components/closures such as doors, roofs, declids, and fenders

Figure 6 shows the steel mapping (HSS and AHSS) from De Moor's dissertation in Demeri, which shows a map of the mechanical properties of two major groups of steel for automotive purposes.

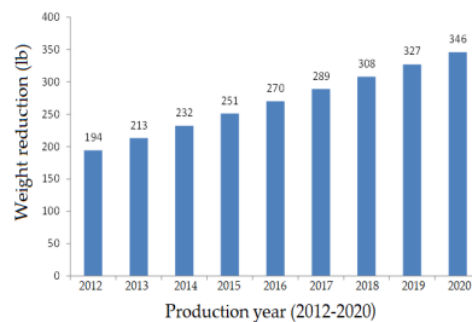


Figure 5. Estimated increase in AHSS consumption for lightweight automotive [20].

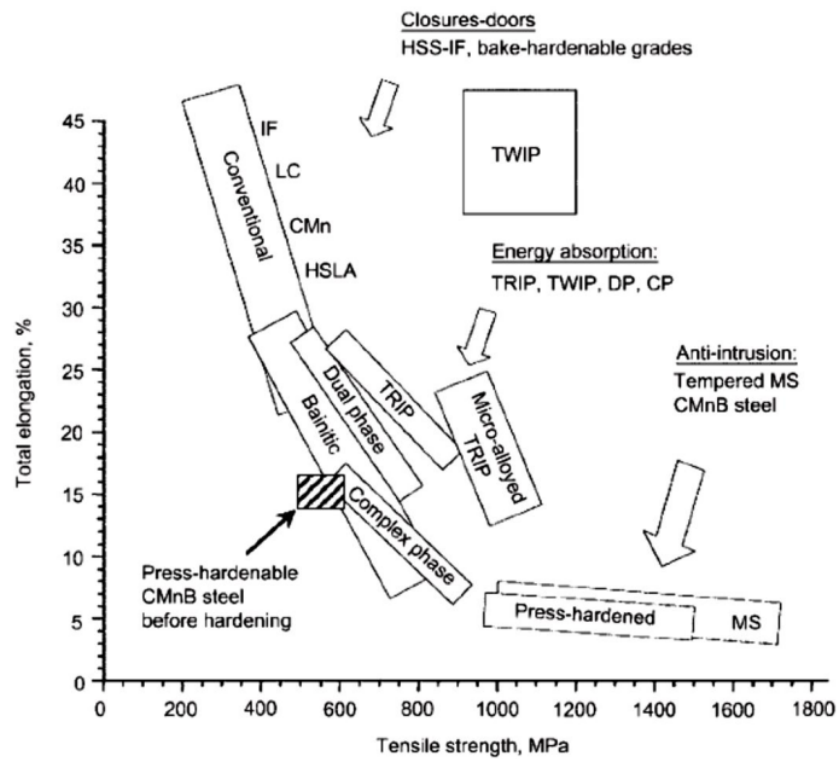


Figure 6. Mapping the type of steel based on its function on the automotive [20].

From Figure 6, it can be seen that the superior mechanical properties of AHSS (≥ 500 MPa) are used to support the BIW function in terms of impact energy absorption (TRIP, TWIP, DP, and CP) and anti-intrusion (MS and CMnB). Whereas

HSS at tensile strength below 500 MPa (IF and BH) function at closures. In more detail, Demeri gives a summary of steel categories (mild steel, HSS, 1st AHSS, and 2nd AHSS) in Table 1.

Table 1. Categories of steel based on mechanical properties [20].

Category	Tensile strength range, MPa (ksi)	Ductility, %	Grade
Mild Steel	< 300 (<44)	30-45	Low-carbon, Interstitial free (IF)
Conventional high-strength steel	300-800 (44-116)	10 -45	Interstitial free, high strength (IF-HS), isotropic (ISO), bake hardenable (BH), carbon-manganese (C-Mn), high strength low-alloy (HSLA)
Advanced high-strength steels (1st generation)	500-1600 (73-232)	5-30	Dual-phase (DP), Transformation-induced plasticity (TRIP), Complex-phase (CP), martensitic (MS)
Advanced high-strength steels (2 nd generation)	900-1600 (131-232)	45-70	Twinning-induced plasticity (TWIP), austenitic stainless steel (AUST SS), light steel with induced plasticity (L-IP)

It was shown in Table 1 that the second generation AHSS has two advantages in mechanical properties, namely strength and tenacity. These two advantages, are not owned by ordinary carbon steel (mild steel) because the inherent nature of steel is the higher the strength will be followed by a decrease in ductility. The same trend was demonstrated by conventional HSS and first generation AHSS. Cross-generational and non-ferrous ferro material applications for OEM products used in America are shown in Table 2.

Despite the competition to produce lightweights, OEM producers still prefer to use ferrous materials (96%) rather than non-ferro (1.7%). It was also known that the AHSS (28.2%) had not yet won its competition against the domination of conventional steel (mild steel, HSS, hot stamp, and bake hardened), which accounted to 67.8%. This condition can be understood because the reduction in vehicle weight must still consider safety factors and driving comfort, especially in energy absorption, when the situation requires it. The amount of 28.2% of AHSS material usage illustrates that the reduction in vehicle weight is still within the limits of safety even though the challenges are still exists. Meanwhile, HSS is more widely used than mild steel, because the price factor which 50% lower. This is because HSS can provide performance comparable to mild-steel, albeit with lesser thickness. This supports HSS which is more economical in terms of raw material prices and process costs.

3. Non-Ferro Material

3.1. Aluminium

Aluminium's contribution to lightweight in the automotive industry has long been recognized in casting products for engine blocks and pistons replacing cast iron and steel, not less than 50% and 100%, respectively. The advantages of this material are in the light weight, corrosion resistance, specific strength, able to melt and the specific energy absorption performance. Its low modulus makes aluminum need metallurgical treatment when substituting steel. However, this metal can contribute in producing lightweights [10]. Aluminium applications are known in exclusive class cars such as Audi A8 (Figure 7) and BMW Z8. Contribute to BIW, reduce 50% by weight than steel, and it can reduce 20-30% of total vehicle weight.

Arnberg's [23] review of 26 automotive components by the Fur Kraftfahrzeuge Institute, found that weight reduction with aluminium can reach 14 - 49%, while with high strength steel it is only 11%. This is because 40% of the analyzed components of steel cannot be made thinner a decrease in stiffness which can worsen the performance of the car. Conversely, which lead to aluminium can increase the fuel efficiency up to 2.7 miles/gallon (10% more efficient than conventional vehicles) without compromising driving safety factors. Aluminium absorbs impact better than steel when accidents occur. Lightweight is obtained without reducing the size of the vehicle. The result, this light weight will consume less fuel so emissions will be lower.

Table 2. The use of Material in OEM products [20].

OEM Products	Ferrous - Non Ferrous Materials						
	Mild Steel	HSS	AHSS	Hot Stamp	Bake Hardened	Aluminium	other
2012 Chrysler Dodge Da	25	30	30	8		4	2
2013 GM Cadillac ATS	17	22.6	34.4	5.7	17.5	2.8	
2013 Ford Fusion	30.5	18	29.2		15.3		7
2013 GM Chevrolet Soni	30	42	19		9		
Sub Total	102.5	112.6	112.6	13.7	41.8	6.8	9
Sub Total/Total Material	25.7%	28.2%	28.2%	3.4%	10.5%	1.7%	2.3%

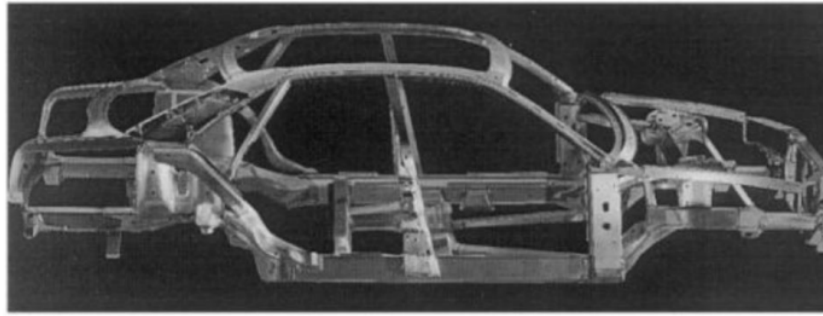


Figure 7. BIW structure on Audi A8 from aluminum extrusion [24].

3.2. Magnesium

The lightest metal-based engineering material on automobiles is magnesium/Mg ($\rho = 1.74 \text{ gr/cm}^3$) gives 36% and 78% lighter than aluminum and steel, respectively. When used in the automotive industry, magnesium has a series of weaknesses in its mechanical and physical properties so it needs to be handled specifically. Magnesium has weaknesses in terms of tensile strength, stiffness, hardness, fatigue strength, and creep strength compared to aluminum.

However, the superiority of magnesium over aluminum lies in its technological properties such as manufacturability, machine capability - capable of producing more precise products, low latent heat - supporting fast freezing, so that the production cycle rate is shorter. Low density, makes magnesium superior to aluminum and steel, in terms of specific strength (ratio of tensile strength to density), which is $14600 > 12081 > 4529 \text{ (Nm/kg)}$ or 14.1% and 67.7% greater than aluminum and steel. In fact, according to the results of a review by Kulecki [25], the use of magnesium alloys can save weight by 20 - 70%. For example, the weight of a dash panel can be saved by 68% to only 9.5 kg of magnesium from the original 30 kg of steel [14]. The International Magnesium Association (IMA) states that the solution to the main problems related to fuel efficiency, improved performance, and sustainability is to increase the portion of magnesium in automotive [26].

Today's vehicle weight reduction solutions with magnesium manufacturing technology have been adopted by several OEMs such as Audi,

DaimlerChrysler (Mercedes-Benz), Ford, Jaguar, Fiat, and Kia Motors Corporation. The gearbox, steering column and the driver's airbag housing as well as on the steering wheel, the seat frame uses magnesium with various manufacturing techniques ranging from stamping, casting and extrusion. Casting technology, for example, is able to integrate several stamping steel components into one single component of magnesium casting with better strength followed by lower processing costs. Figure 12 shows the BIW Venza 2020 component using magnesium casting (No. 2 to 5).

In addition to the advantages in terms of weight reduction, today magnesium has contributed to vehicle performance in terms of improving handling and turning capabilities. This is because the center of gravity of the vehicle shifts to the rear due to decreased load at the front end of the vehicle after the use of magnesium [26].

4. Polymer Composites

Polymer composites are combination material made from polymer/resin matrices (thermoset or thermoplastic) and reinforcing components/fiber (glass, carbon, or natural fiber). Polymer composites with fiber (glass fiber reinforced (GFRP) and carbon fiber (CFRP), with their specific mechanical advantages, have supported the automotive lightweight (Figure 8a). Since Henry Ford in 1941 introduced GFRP in the automotive industry, the number of automotive components up to 2013 according to Web of Science data (Figure 8b) reaches nearly 350 items, supporting lower densities than ferrous and non-ferrous metals, making polymer composites able

to compete in fuel savings to reduce carbon emissions.

Vehicle design with 100 pounds of thermoplastic composites and pure polymers, is estimated to save 1892 liters of fuel/year with an assumed distance of 40 miles/day [27]. Meanwhile, statistical data from the Japanese Ministry of Transportation reported in Ishikawa's research, states that reducing 100 kg of vehicle weight can save 20 grams of CO₂ per km travelled. Komornicki reported that GFRP can save weight between 15-25% while CFRP is between 25-40% compared to steel or aluminium.

The estimated reduction of CO₂ emissions in the European Union could reach 8 million tons/year, assuming a 33% weight reduction in 10% of the total vehicle volume. From this estimate, the European Union relies on CFRP to reduce CO₂ emissions. Meanwhile, Japanese NCC research results for carbon fiber reinforced thermoplastics (CFRTP) have only reached a 10% reduction in weight. The global composite market recorded an increase of 7% per year during 2011 - 2017 from 2.8 million to 4.2 million USD [28]. The successful practice of applying polymer composites has removed the constraints of

fabricating polymer composites two decades ago [29], such as lack of industry experience, understanding of composite responses and the level of process difficulty, recycling technology, and the high price of carbon fiber.

Polymer composites (FRP), unlike metals which have the same properties in all directions (isotropic), but are anisotropic, that is, have maximum strength in the direction of fiber orientation. That is, the strength of the polymer composite can be designed in the direction of loading. This is the advantage of FRP, besides being lightweight, corrosion-resistant, durable, easy to maintain and stable dimensions. The nature of FRP, in addition to being influenced by manufacturing techniques, is also determined by the type and volume fraction of its constituents, namely fibers and matrices. More specifically, FRP design parameters are type, volume, and fiber orientation, resin type, operating conditions, process costs, manufacturing, and production volume [28]. The development of polymer composites in several vehicle models in Table 3 shows the dominance of CFRP, which confirms the progress of FRP manufacturing technology.

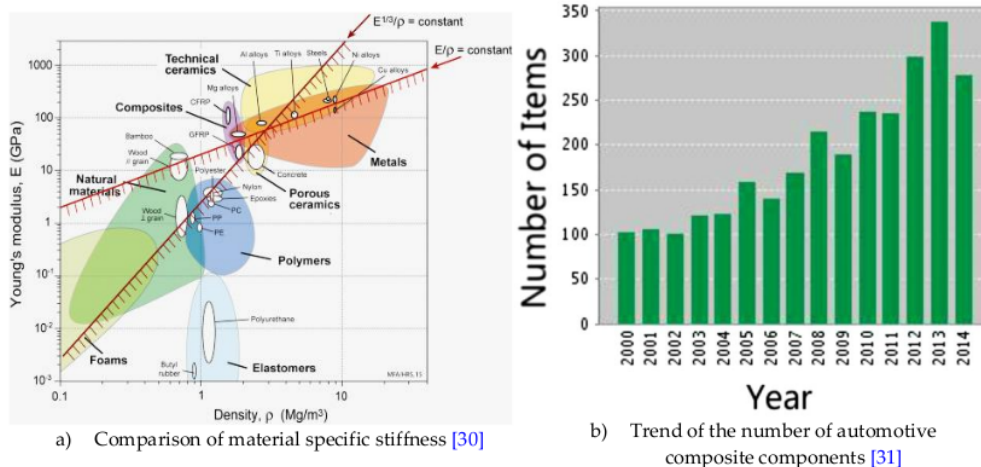


Figure 8. Specific stiffness and trends in composite materials in automotive parts

Table 3. Application of polymer composites in components of several vehicle brands [28].

OEM-Model - Year	Application	Material
BMW i3 - 2013	Passenger cell	CFRP
BMW i8 - 2014	Passenger cell	CFRP
Alfa Romeo 4C - 2013	Chassis	Prepreg (CF, epoxy)
	Outer body	SMC
	Bumpers and mudguards	CF + PUR RIM
BMW M6 convertible - 2013	Roof compartment, trunk lid	GFRP
BMW M6 Coupe - 2012	Car Roof	CFRP
Lexus LFA - 2012	Cabin, floor, roof, pillar, hood	CFRP
Lamborghini LP700-4 - 2012	Front/Rear bumpers	CFRP
	Body aerodynamic kit	CFRP
Land Rover - Evoque - 2011/12	Instrument panel, inner door modules	GFRP

RIM: Resin Injection Molding, PUR: Polyurethane, SHM: Sheet Molding Composite

5. Automotive Light Weight

In this section, a brief review is given regarding automotive lightweight estimation. Reference is given by Lotus to the type of 2009 Venza vehicles that have been produced [14]. Venza 2017 and Venza 2020 in each of the Low-Development (LD) and High-Development (HD) schemes are given as a comparison to Venza Baseline (2009) to see the effect of changing material applications on reducing vehicle weight and production costs. Venza is a 5-passenger, 4-door capacity car, made with 4-WD or FWD / Front Wheel Drive configurations and 4 or 6 cylinders. For Baseline, 2700 cc 4-cylinder Venza FWD was chosen with fuel consumption rates of 21 and 29 MPG for each use in and outside the city.

Mass reduction is made by increasing modularisation, replacing mild steel with ferrous metals (HSS and AHSS), non-ferro (Al and Mg), and composites. Also, metal manufacturing techniques such as metal extrusion and metal casting are also applied to reduce the number of components without reducing the material strength needed to support vehicle performance.

5.1. Optimization of Baseline to Low-Development (LD)

Figure 9 shows the percentage of mass distribution at the Venza baseline, which is

identical to the LD and HD schemes. The review is limited to the body section only, considering that three other dominant sections (Chassis, Interior and Closures) are in the process of peer-reviewed articles related to biocomposites and nanocomposites [32].

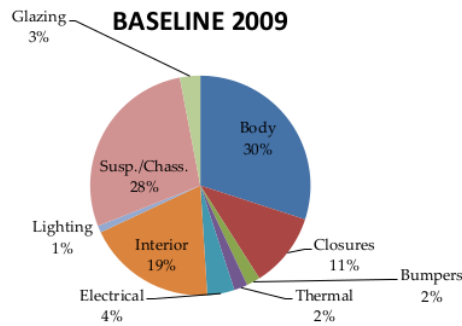


Figure 9. Mass distribution of components for each Venza baseline section [14].

In Figure 10, the predominance of ferro material (HSS and AHSS - Table 1 / Figure 5) along with the weight fraction is shown for the framework/BIW baseline and LD schemes. BIW/body-in-white is the result of stamping and weld shop. The number behind (eg DP 590) is the minimum yield strength, 590 MPa.

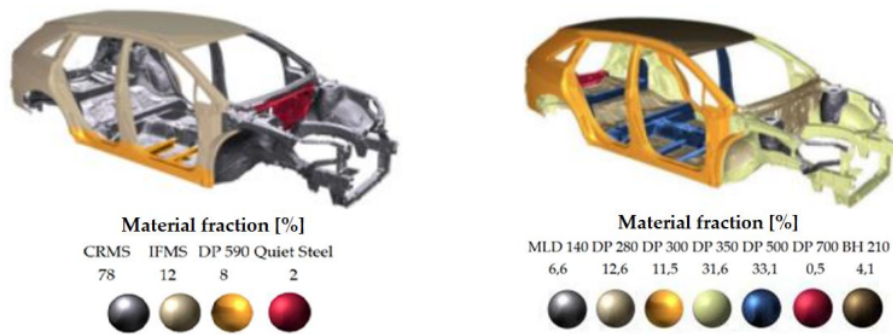


Figure 10. Weight Fraction of Materials in BIW for Baseline (left) and Low Development (right)

The material fraction in Figure 10 is obtained from the results of body scans which are then modelled to calculate the area of each panel section. The thickness of the panel is measured by the ultrasonic testing (UT) method, and its chemical composition is tested using the spectrophotometry method. The resulting structure was verified by a team from the United States Steel Corporation to determine the type of panel material and its density. From the thickness, area, and density of panel material, the weight fraction of each material is calculated. Figure 11 shows the material change from Baseline to Low-Development (LD) mode.

The main baseline material is 90% mild steel (CRMS and IFMS) plus 10% AHSS (DP 590 and QS). While in LD mode, the portion of mild steel is reversed to 10.7% (MLD and BH) and 89.3%, the rest is AHSS. Material in the baseline mode is

intended to support the primary function of Venza while LD is intended to achieve light weight (DP 280 -DP 350), followed by the ability to absorb impact energy during an accident (DP 350-DP 500), deformation resistance (DP 700), and scratch resistance on the outside (BH).

In terms of density, the change from baseline to LD has not resulted in much reduction in Venza weight because both material groups have the same base, ferrous metal. However, from the aspect of material strength, a weight reduction can be seen due to the decrease in material volume due to reduced thickness to achieve the same strength. That is, a reduction in material weight has occurred, but still needs to be optimized. Therefore, a second scenario is created by designing a High-Development (HD) scheme to see opportunities for more optimal lightweight.

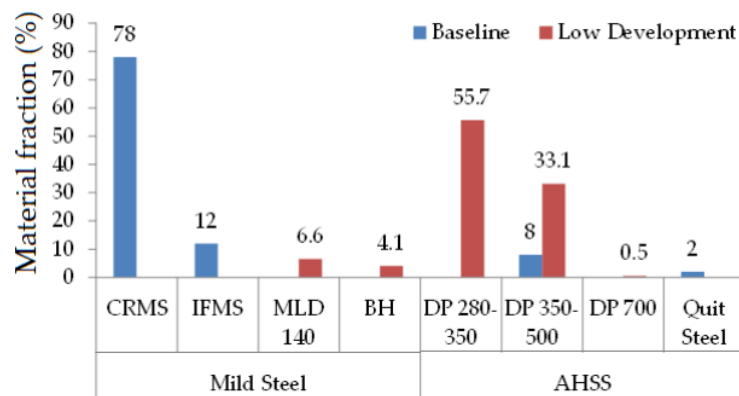


Figure 11. Changes in the use of ferro materials from Mild Steel to AHSS

5.2. Optimization of Low-Development to High-Development (HD)

In this HD scheme, a combination of ferro, non-ferro and composite materials is planned to achieve a lighter Venza weight than the LD scheme. Material selection is directed by simplifying the manufacturing process, integrating separate components, simplifying assembly, and maintaining functionality. LD motivation refers to the European Super Light Car (SLC) project team that has succeeded in reducing

364% by weight in the 2005 VW Golf from 281 kg to only 101 kg or through a combination of steel and non-steel material.

The HD scheme starts by determining the structure and function requirements, including the consideration of bending and torsional rigidity, impact energy loading patterns, and vibration modes. To further optimize weight reduction, the BIW in the HD scheme is divided into five main sections (no. 1 to 5) in Figure 12.

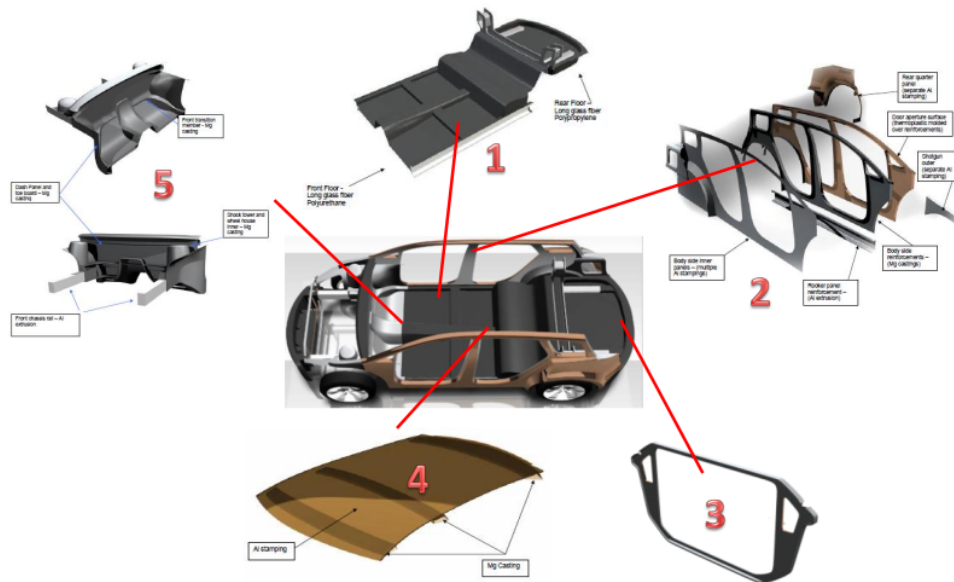


Figure 12. Magnesium casting technique and division of BIW components in High-Development mode

Weight reduction is given by Molded Panel Floor (1) made from GFRP polypropylene and polyurethane matrices. Other BIW parts (2 to 4; Body Side, Front end module, Roof, Dash and Front panel) use a combination of magnesium casting, aluminium stamping and extrusion techniques to support the achievement of lightweight. Obtaining a weight reduction result of 382.5 kg is more significant after the HD scheme (42%) than LD (15.9%). This result was followed by changes in HD and LD production costs by 135% and 98% over 100% Venza baseline production costs, respectively. From these results, to make efficient use of fuel and reduce carbon emissions 35% additional production costs for

Venza 2020 products are needed. Furthermore, according to the data in Figure 1, a 42% weight reduction in the HD scheme will contribute to a 12.6% reduction in total weight Venza. The results of the Massachusetts Institute of Technology study states that 35% reduction in vehicle weight is included in the safe category and can save fuel consumption between 10-20% [9].

According to Ishikawa [33], a 10% reduction in the total weight of a vehicle can save 20 gram CO₂/km, so this 12.6% reduction in total Venza weight will contribute to a reduction in CO₂ emissions/km of 25.2 grams. That is, during its useful life, Venza can save 3.65 tons of CO₂. The assumption for the use of Venza 10 years with

average mileage/day of 50 km. If the figure of 3.65 tons of CO₂ is confirmed by data [22], that a saving of 3 to 4.5 tons of CO₂ is equivalent to compensate for CO₂ emissions during vehicle production, Venza has fulfilled the zero-emission CO₂ criteria. From this, it can be concluded that the 35% additional Venza HD production costs are very minimal when compared to fuel savings and carbon emission reductions over the lifetime of Venza.

6. Conclusion

The level of reliability of ferrous, non-ferrous, and FRP materials has been reviewed in this article. The choice of ferro material (mild steel, HSS and AHSS), non-ferro (aluminium and magnesium alloys), and FRP has been proven to reduce the total weight of the vehicle up to 12.6% or equivalent to the contribution of CO₂/km emission reduction by 25.2 grams. Confirmation of this number for statistical data from the literature illustrates the possibility that lightweight material can reach zero CO₂ emission. Likewise, with consideration of the safety and durability of the vehicle, this 12.6% weight reduction is still within safe limits.

7. Future development

Optimistic findings from the study of vehicle light weights have been revealed a bit in this article. However, it needs to be understood that this is only an initial hypothesis based on literature. If indeed this optimism is in accordance with predictions, then further studies still need to be done to get other material opportunities that are able to provide zero CO₂ emissions, without having to wait for the end of life of the vehicle. In this regard, preliminary research into biocomposites has been carried out and is currently continuing at the nanocomposite level [32].

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