Lightweight High Performance Materials for Car Body Structures

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Abstract

The choice of materials for vehicle components is dependant on a specific supply and demand process, subject to a stringent set of requirements. Among other things, this includes economic effectiveness, safety, recyclability and lightweight performance. Metals such as steel, aluminium and magnesium are mainly used for elements of the body structure and panels. Plastics are applied for exterior attachments to the body. Cars consist mainly of steel and iron, but it is expected that the amount of steel and iron used is reduced due to the impending use of multimaterial constructions. Materials such as steel will be substituted, in particular by aluminium, magnesium and plastics. Alternatives to the steel unibody are multimaterial unibodies and aluminium space frames. Steel and magnesium space frame concepts for volume applications are still under development. More traditional materials are being replaced by high performance carbon fibre composites for their durability and specific strength/ stiffness.

Introduction

Not so long ago cars were almost exclusively made from iron and steel. The automotive industries were looking for cheaper and easily accessible materials for their products. But the factors such as brutal competition as well as a governmental push for lighter, more fuel-efficient vehicles has led to the introduction and continued implementation of aluminium, plastics and a host of various composites. The car industry is facing a huge global challenge: to reduce fuel consumption and minimize Carbon Dioxide emissions accordingly. Therefore lightweight technology plays a key role in this context. Many Car manufacturers are trying to meet the challenge by developing new technologies, materials and processes in order to further improve the efficiency and ecological balance of their cars, whilst naturally maintaining a good standard of customer benefits.

The challenge for car makers is to produce inexpensive, environmentally conscious vehicles that are safe, attractive and economical to operate. Fuel efficiency stimulates usage of lightweight materials in automotive industry. Lightweight materials are now being used as substitute for the traditional automotive materials because of its abilities to increase the fuel efficiency as well as reduce the emission of harmful pollutants, without compromising performance, size and utility. Theory also revealed that 10 per cent reduction in vehicle weight can lead to an impressive 6 to 8 per cent improvement in fuel usage. The 75% of fuel consumption depends upon the vehicle weight therefore the lighter vehicle consumes less fuel compare to heavier vehicle. An assumed reduction of fuel consumption of approximately 0.3 to 0.4 litres per 100km could be achieved by a weight reduction of 100kg[1,2] . The body of a car, including the interior, accounts for nearly 40% of the car’s total weight and offers a high potential for lightweight construction. If the body mass is reduced, in theory, a secondary mass reduction can be realised. For example, the chassis, brakes and gears

can be designed to be smaller and lighter, resulting in a reduction in the weight of the car[3].
Measures of attaining lightweight constructions can be separated into the following three types.

- The first type of lightweight construction is to replace materials of high specific weight with lower density materials without reducing rigidity and durability. Common lightweight materials are, for example, metals such as aluminium, magnesium, high strengthened steels, foams or different types of unreinforced and reinforced plastics.

- Structural lightweight construction implies that load-carrying elements and exterior attachments are optimised in their design so as to reduce their weight without any loss in rigidity or functionality.

- Another way of realising lightweight constructions is to optimise the production process. First of all, the reduction of spot welds should reduce the body weight when replaced by new joining techniques such as laser welding or manufacturing processes such as hydroforming.

Application of modern Materials
Steel

Today's most commonly used materials for vehicles are still different types of steel. They offer a wide variety of material characteristics such as thermal, chemical or mechanical resistance, ease of manufacture and durability. The development process on steels continuously creates new materials for applications within the automotive industry with improved characteristics. These high strength grades are increasingly used in the high-volume production for parts such as sheets or profiles, which are assembled by special manufacturing techniques. Higher-strength steels currently account for 80% of the body of a European premium-class car such as the BMW 7er-series, introduced in 2001[4].In parallel with the enlarged use of this material, the yield stress of high-strength steels has been improved over the years, realising 220 megapascals (MPa) up to 1,400MPa. Today, higher-strength steels are similarly being used more frequently in smaller vehicle segment as well.

Aluminium:
Aluminium has already established itself in the car industry for many years. Its low density and high specific energy absorption performance and good specific strength are its most important properties.

Aluminium is also resistant to corrosion and can be easily recycled in its pure form. Due to its lower modulus of elasticity, it cannot substitute steel parts on a one-for-one basis. Therefore, those parts need to be engineered to achieve the same mechanical strength; however, using aluminium still offers potential for weight reduction.

Aluminium is used for body structures, closures and exterior attachments such as crossbeams, doors or bonnets. Pure aluminium bodies have been developed and implemented. They are mainly used for luxury cars, such as the Audi A8, and some niche vehicles, such as the BMW Z8, because of their comparatively high material and production costs.

Plastic:
Plastics are already an important material for the automotive industry. It has a low density, are mostly economic to produce and their characteristics can be fitted to specific demands. The wide variety of properties can be created through chemical or physical material combinations due to this plastic is gaining its popularity among the car industries in both passenger cars and racing car industries. Plastics can be classified into unreinforced and reinforced plastics. Unreinforced plastics can be used to make bumper coverings or exterior attachments to the body structures. Due to their weak mechanical characteristics, plastics will not frequently be used for large-scale structural components such as vehicle floors. The forming process provides the opportunity to create complex three-dimensional (3-D) structures.

Reinforced plastic reduces the mechanical weakness of unreinforced plastics. The base material (e.g. unsaturated polyester, polyamide or epoxide) can be reinforced by short or long fibres made of different materials such as glass, aramide or carbon. Due to the specific properties of fibre reinforced plastics (FRPs), parts such as body structures for energy absorption can be realised.

Currently, FRPs are relatively expensive to produce and are mainly used in some niche vehicles (e.g. Aston Martin Vanquish).

The research to manufacture complete plastic bodies is continuing. In contrast to vehicles with conventional steel bodies, vehicles made with plastic bodies provide clear advantages in terms of weight reduction up to 60%. This massive weight reduction offers the opportunity to reduce weight for example of power train and chassis components resulting in less stress. However, applications in this area for volume production are still under development.

Magnesium
Magnesium is another light metal that is becoming increasingly common in automotive engineering. It is even lighter than aluminium and is already used in the manufacture of transmission housings or parts of doors and bonnets for lightweight constructed cars. Magnesium constructions for these components are of sufficient strength and ensure substantially lighter parts than aluminium ones. Due to some material specific difficulties in stamping and forming magnesium parts, components of magnesium are primarily produced by pressure die-casting, which permits the manufacturer to create parts with complex geometries. This manufacturing technology makes it possible to integrate a diverse set of functions into a single component in one manufacturing step.

Advanced composite materials

Fibre reinforced composites offer a wide range of advantages to the automotive industry. It has been popular due to its most widely recognised benefit that the potential for weight saving offered by their low density. As it is discussed that reduced weight could lead to lower fuel consumption, with all the economic and environmental implications that brings. However, the following are the range of other economic benefits:

Component designs can be such that the fibres lie in the direction of the principal stresses, and the amount of fibre used is sufficient to withstand the stress, thus optimising materials usage. It is very vital advantage for the racing car application where the impact load as well as principal stresses come to in business.

The design and fabrication routes can be combined so that complicated shaped components can be moulded in one process rather than being assembled from components or machined from blank, potentially reducing manufacturing costs.

Composites can be fabricated relatively easily at low pressures and temperatures of no more than 200°C, which again has implications for production costs.

The excellent resistance to corrosion and other chemical environments could help manufacturers to prolong the lifetime of individual components and whole vehicles. The latest composite technology yields great advantages over traditional materials in car industries mostly in Formula 1 car industry. The rapidly advancing commercial market demands stronger and lighter materials capable of optimum component performance, beyond the characteristics of conventional materials.

Carbon-fibre epoxy composites:

Most recently, the most of the racing car companies much more rely on composites form whether it would be plastic composites, Kevlar and most importantly carbon-fibre epoxy composition. It is because the composite structures is the high strength/low weight ratio, which particularly benefits racing car structures, where any weight saving is beneficial, and necessary for improved performance or competitive advantage.

The literature also revealed that the racing car companies, especially for Formula 1 cars, are moving further in the research and development of different composite in the direction of complex, high performance, moulded composite structures, manufactured in a variety of pre-impregnated materials, and more vitally can be cured at temperatures up to 200 degrees centigrade. The most common materials used for racing cars are carbon (graphite), Kevlar and glass fibres, pre-impregnated with high temperature epoxy resin. Most components have a light weight honeycomb core for maximum weight/strength ratio, with inserts designed and manufactured from a variety of materials to give the necessary support in local areas where drilling, bolting or bonding to other structures is required.

The basic chassis of a Formula 1 racing car is a monocoque construction which has three layers. Two of the layers are made using a plastic resin reinforced with carbon fibre. These two layers are the inner and outer skins and the interior layer of aluminium honeycomb sandwiched between the inner and outer layer. This structure extends from the nose cone to include the driver's cockpit and the section behind this which houses the fuel tank. The engine and gearbox are bolted to this and themselves form part of the complete car chassis.

Carbon fibre reinforced epoxy is used to construct the outer skin by building up several layers of carbon fibre reinforced epoxy in a mould. (The mould itself is also made of carbon fibre reinforced epoxy, which in turn relies on another type of plastic for its manufacture.) After heat treatment, the honeycomb interlayer is fixed in with a sheet of resin, followed by more heat treatment and the application of the inner layer.

The research in different types of composites materials shows that the epoxy resins allow fabrication of composite materials with mechanical and thermal performances comparable or higher than metal for structural applications. After successful demonstration in aircraft construction, epoxy composites have become the first choice in Formula 1 car industries and other race cars.

Automotive industries are pursuing further development in epoxy composite materials in serial car production. The major advantages that automotive industries seeking is in primary weight reduction and fuel efficiency. The combination of low specific gravity which is 4 to 5 times less than carbon reinforced composites, associated with high mechanical strength and stiffness authorises lower weights. Significant cost reduction in composite manufacturing processes as well as a drop in the price of fibre materials makes it possible.

The manufacturing processes of epoxy composite materials that used in Formula 1 car production also needs to be adapted according to the mass production. The Resin Transfer Moulding (RTM) processes allows one step production of parts. This technology is chosen for the production of structural, load bearing parts like chassis. RTM allows the production of reproducible high quality parts within acceptable cycle times with suitable Epoxy resin system. Furthermore, the flexibility of this process authorises new design ideas which is not possible by using metal construction.

Plastic Composites:

Plastic composites are also one of the popular materials among composite family in Formula 1 racing cars chassis. Plastics composites are so light that the average F1 car is lighter than the minimum weight permitted by the Federation Internationale de l'Automobile (FIA). The lighter chassis gives the opportunity to the designer to have a control over weight distribution over the heavy components such as engine and gear box which are located rear of the car.

Plastic is making an inroad into the chassis market. Innovations in plastic technology have brought about the development of successful chassis applications that would not be possible using any other family of materials.

Plastic is being adapted by the modern automotive world because of its lightweight and shocks absorb ability. For instance, the world's second all-plastic vehicle, the Baja, has a plastic composite chassis. The vehicle is ideal for off-road tropical environments where its composite body and chassis resist sand and seawater. Its combined thermoplastic and thermoset skin and frame take advantage of plastic's strength to manage energy, enabling it to pass both the United States' and the more stringent European computerized crash tests. The chassis' light weight is a tremendous advantage to manufacturers, since weight savings makes parts easier to transport. It also provides consumers better fuel economy. Since plastic and plastic composites have only recently been considered for use in frames, there is not yet a track record as to what types may be best suited to these applications. Experiments with plastic in frames may lead to future innovations enabling plastic to replace metal on a broader scale.

For example, Crash-absorbing foam is a well-tested application. It is done by filling the door panels with rigid, energy-absorbing polystyrene or urethane-based foam that acts as side impact absorbers and help maintain a car's structural rigidity. These lightweight foams provide excellent energy management capability during a crash.

Glass-fibre Composites:

Glass fibre is being used mostly for the sports car which includes Formula 1 cars. It is lighter than steel and aluminium, easy to be shaped and rust-proof. Furthermore, importantly, it is cheap to be produced in small quantity - it needs only simple tooling and a pair of hands.

Glass-fibre mostly used in British sports car industries because it is cheaper to make in small quantities. However, it was very difficult to get very small tolerances in glass-fibre that required between connecting points between the glass-fibre body and suspensions / engine.

Today, Lotus, TVR, Marcos, GM's Corvette / Camaro / Firebird, Venturi etc. has implied glass-fibre in non-stressed upper body which helps to get tolerance between the connecting points, as it discussed, more easily than Lotus has done in 1957. In other words, they just act as a beautiful enclosure and provide aerodynamic efficiency. The stressed chassises are usually backbone, tubular space-frame, aluminium space-frame or even monocoque.

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