



THE ROLE OF LIGHTWEIGHT MATERIALS IN MODERN TRANSPORT VEHICLES

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Abstract

Polymeric materials and their composites in vehicles have experienced a real boom in the last 30 years, and their application is increasing with a tendency to further growth. The demands on the modern vehicle industry, whether they are trains, planes, or cars, are ever challenging – users want high-performance vehicles, but at the same time they are looking for improved reliability and safety, greater comfort, and low pricing. Changing the proportion of light-weight materials to steel in the construction of new vehicles helps make them lighter and more fuel or electrical energy efficient, resulting in lower greenhouse gas emissions. There is one family of materials that is responding to the challenge of these potentially conflicting demands: polymer materials. This includes relatively pure chemical materials as well as fibre-filled polymer composites. This article presents polymeric materials that are used for the production of vehicle parts today

Keywords: transport, polymer, materials, plastics, composites.

1. INTRODUCTION

Transport is a permanent feature of human development. It constitutes a kind of "blood circulation" of society, performing the functions of goods distribution, people transport, and facilitates knowledge exchange and dissemination of key information. The contemporary development of transport and the increasing demand for this service make it currently one of the most significant factors in the development of civilization. It is an important part of the economy in Poland, as well as in all other places in the world.

Polymeric materials, commonly referred to as "plastics", "plastic resins", or "polymer materials", are a wide range of engineering materials. In a modern motor vehicle, we can find several types of polymeric materials.

Some are used in reinforced form to form so-called composites, while others are used in pure form. Modern vehicles, in terms of construction, are made of steel, aluminium, and a host of different polymeric materials. In the most modern of them, even load-bearing elements or elements responsible for the safety of the driver and passengers are made of polymer composites.

Steel, especially high-strength steel, is still the dominant material in motor vehicles. On average, steel components account for more than half of the weight of a vehicle. Other heavy metal components, such as cast steel and cast iron, are gradually being displaced from vehicle construction. However, at the

moment, steel and cast iron elements together account for around 60% of the average vehicle weight. And remember that in the 1990s this value was more than 10% higher [1].

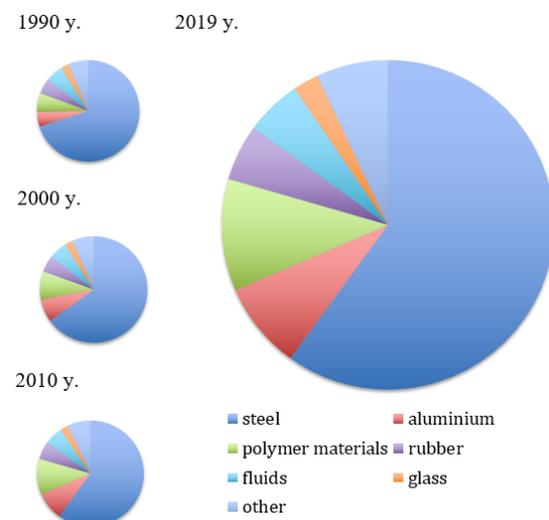


Fig. 1. Weight share of different materials in the mass of a motor vehicle in the last three decades (own compilation based [1,2])

Over the past few decades, lightweight materials have gained increasing acceptance in the construction of automobiles. For example, aluminium currently accounts for 10-11% of the average weight of a motor vehicle [1].

During this period, other lightweight materials, such as magnesium and polymeric materials and their composites, have also gained weight share in vehicles. Details of the materials used in vehicles are shown in Figure 1.

In the discussion presented here, the weight of elastomers has been collated under a separate heading 'rubber', as this is an almost invariable compartment associated with the weight of tyres, gaskets, and fuel hoses. In contrast, the "other" heading includes nonferrous metal alloys such as copper and brass, lead and zinc, etc. Glass, coatings, textiles, fluids and lubricants, and other materials complete the composition of a typical motor vehicle [1].

The proportion of polymeric materials in the total weight of a vehicle has increased significantly over the last half century. While in 1965 a medium-sized passenger car consisted of 85% different types of metals and about 2% polymeric materials, 20 years later metals accounted for only 75% of the mass, while polymeric materials increased their share 5 times [1,2]. Today's polymeric materials account for about 50% of the volume of a new vehicle, which sometimes does not even account for 10% of its weight (Figure 2). This disproportion of volume and weight share is due to the low specific gravity of polymer materials, which in some cases is less than 1 g/cm^3 and usually does not exceed 2.5 g/cm^3 . In comparison, the steel density is 7.8 g/cm^3 .

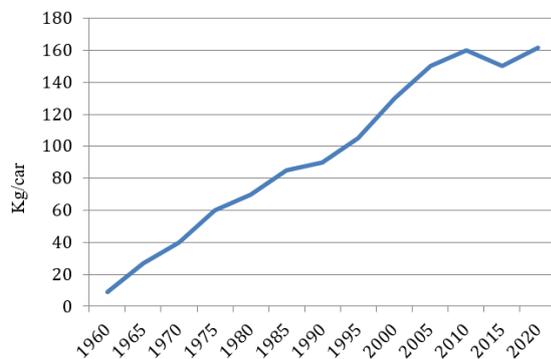


Fig. 2. Number of kilograms polymer materials in an average car (own elaboration based on [1,2])

Changes in the proportion of 'lightweight materials' relative to steel in the construction of new vehicles help make vehicles lighter and more fuel efficient, resulting in lower greenhouse gas emissions. Reducing the weight of a vehicle by about 100 kg results in a reduction in fuel consumption of 0.3 to 0.6 l / 100 km and a reduction of 7.5 to 13 g/km in CO₂ emissions [1,3]. The global share of road transport in total CO₂ emissions is approximately 20% (passenger cars account for approximately 12 %) [3]. Not surprisingly, it is necessary to take all measures aimed at reducing greenhouse gas emissions.

Electrically powered vehicles also benefit from the use of polymer materials, as by reducing their

weight we increase the range of the vehicle to a single battery charge. In addition, extensive work is being carried out jointly by the automotive and electrochemical industries to develop a lithium-polymer battery. Such a battery, which uses a lithium alloy and conductive polymer, is flexible to a certain extent, can be of almost any shape, and is, above all, lighter. Despite the widespread use of such energy storage sources in consumer electronics, the construction of such a battery, conceived as a power source for electric cars, still faces serious technical and economic difficulties [4].

Apart from the main reason for the use of polymeric materials, i.e., the low-weight part with good mechanical strength, there are several other reasons for the popularity of these materials in the automotive industry. These are [3,5,6] :

- ability to dampen noise and vibrations,
- the increase in passive safety,
- lower production costs due to different and efficient manufacturing techniques (e.g., injection moulding),
- increasing passenger comfort,
- providing high interior aesthetics,
- fulfilling decorative functions (logos, decorative stripes, etc.).

The large share of the automotive industry in the market demand for polymeric materials has been observed for many years (Fig. 3). In the last decade, the European automotive industry has been a customer of between 3.5 and 5 million tonnes of various polymeric materials. At the same time, it is the third market, after packaging and construction, for these materials. This structure of the economy means that in recent years, depending on the economic situation, this market has occupied between 7 and 10% of the total polymer materials industry [7].

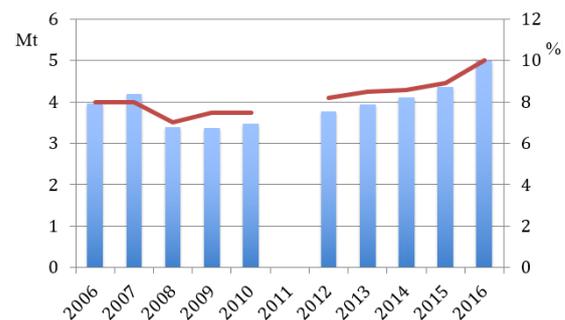


Fig. 3. Consumption of polymeric materials by the automotive industry; bar - market share in Mt, line - market share %; 2011 - no data available (own elaboration based on [5,7])

2. POLYMERIC MATERIALS IN THE VEHICLE INDUSTRY

Both curable thermoplastic and elastomeric polymeric materials are used for vehicle parts.

Curable polymeric materials are used in the form of mixtures of polymers and fibrous fillers to form composites. Usually, the matrix is epoxy resin and the fillers are carbon fibre, glass fibre, aramid fibre, and sometimes fibres of plant origin. Less common is the use of polyester or vinyl ester resins. The lower costs of polyester or vinyl ester resins compared to epoxy resins favour the use of the former. However, mechanical and thermal properties, high moisture resistance, low shrinkage, and high elongation favour epoxy resins [8,9].

Thermoplastics are the most popular group of polymeric materials. Their specific feature is the ease of shaping in technological processes, the possibility of recycling, and, above all, their low density. The ease of shaping makes it possible to manufacture large and precise components, such as a car bumper.

Elastomers are materials with high elasticity and are commonly known as rubbers.

Despite the countless different polymer materials, the industry uses only the characteristic and most popular materials for products. For example, the automotive industry uses only 13 of them in large quantities. All of these thirteen can be used successfully in a single automotive vehicle, but only three types account for 66% of all polymeric materials used. These are polypropylene (PP) (32%), polyurethane (PUR, TPU) (17%), and polyvinyl chloride (PVC) (16%) [5]. Less used plastics are various types of polyamides (mainly PA 6 and PA 66), polystyrene (PS) and its two copolymers ABS and ASA, polyethylene (mainly HD PE), polyacetal (POM), polycarbonate (PC), polyethylene terephthalate (PET), polymethylmethacrylate (PMMA) and polybutylene terephthalate (PBT) [5]. Most of these materials are thermoplastics.

Polymeric materials can be found in many forms in vehicles. Pure plastics, or modified with chopped glass fibre, are used to produce parts of varying sizes; however, these are usually low-stress components.

The second group is structural parts/elements. There are two solutions here. Polymeric composites or hybrid elements are used.

Polymer composites use continuous fibres, in the form of mats, fabrics, roving, or spatial structures, as the carrier component, while the stiffness of the material is provided by the polymer resin, which is also the binder that binds the fibres together. Through the use of various technologies, the two components are combined to form a strong and rigid composite structure.

Hybrid elements are parts in which strength is ensured by adequate bonding of usually two elements together. An example of this is a girder, the shell of which is made of thin sheet steel, and the ribs are made of polymer materials. Together, they form a light, strong, and economical structure, replacing heavy steel elements.

2.1. Examples of the application of polymeric materials in vehicle

Today, polymeric materials are indispensable in the manufacture of all means of transport. For a long time, in vehicles, they were only used for the interior of the vehicle or for parts that protrude above the body of the vehicle such as bumpers, mirrors, spoilers, and door trims. Nowadays, however, they are increasingly being used to manufacture parts previously reserved exclusively for body sheet metal. Polymeric materials are already used to manufacture doors, wheel arches, mudguards, or hoods.

A typical vehicle may contain more than 1000 parts made of polymeric material. Some automotive parts made from this group of materials are listed below [1,3,5,9,10]:

- dashboard components and upholstery
- car seats (frame - ABS, backrests - PA, cushions - PUR),
- clutch pedals, accelerator pedals (PA filled with glass fiber), mirror housings, upholstery mounting clips, elements of vehicle ventilation and heating systems, etc.
- heating of the vehicle interior, etc.
- bodywork elements (mudguards, large areas of bodywork),
- bumpers, which are currently an integral part of the front and rear of the car, are now made of modified PP, PC, or PBT,
- lamps - front and rear (mainly from PC),
- other components, such as exterior mirrors, wheel covers, air intakes, etc.
- fuel tanks, made of HDPE and POM, have been used since the 1960s,
- Engine and engine accessories. Parts belonging to this group include, among others, timing belt tensioners, air filter housings, intake manifolds, cooling system components such as radiator tanks, heat exchangers, expansion tanks, thermostat housings, shaped tubes, radiator fans, or their housings. Most often, these components are made of polypropylene (PP) or polyacrylamide (PA), modified with chopped glass fibre.
- Another group is composed of components subject to mechanical loads. They include bearing baskets, gears for camshaft drives, speedometer drives, chain tensioners, etc. The construction of these elements is dominated by polyamide. Polyamide with glass fibre predominates in the construction of these components;
- components coming into contact with fuel (fuel injector housings, seals in fuel metal pipes, seals in fuel injection and cooling water pipes, seals in fuel lines, etc.);
- in metal fuel lines, fuel rails of engine supply systems, etc.) are usually made of PA 66 or POM modified with chopped glass fibre;

- tires - in this case, it is difficult to speak about the diversity of elements. In this group, we are dealing with tires that have been inextricably linked to motorization since their beginnings. The material from which they are made is rubber, i.e. a composite of elastomers, carbon black, sulphur, wire or fibre reinforcement, etc.

2.2. New trends in polymeric materials for the vehicle industry

The search for new polymeric materials is heading in the direction of finding a material that is lighter than steel but still has high mechanical strength. The easiest way to find such a material is to modify existing polymeric materials. Such a solution has at least three advantages.

Firstly, we use materials that are produced in abundance around the world and, therefore, are cheap. We do not have to create new chemical installations for their synthesis; we can use a wide range of base material producers, and there is also a wide range of modified materials to offer.

Secondly, we use proven processing technologies. Here, too, we reduce production costs: The market for processing machine manufacturers is large and tailored to the most popular polymer materials.

Third, physical modification, unlike the synthesis of new polymeric materials or their chemical modification, is a relatively easy process.

For these reasons, the use of polymer composites for structural components is an obvious choice. The resulting material is ten times stronger than the steel used in the automotive industry and eight times stronger than aluminium. In addition, it is significantly lighter than both metals.

In the currently evolving technical progress, one can increasingly see the use of composite materials, in the aspect of advanced design solutions of most modern aircraft (Airbus A-380, Boeing B-787, SJF F-35, UAV) [11]. Applications for composites include not only aircraft, but also yachts (mainly polyester-glass), trains and cars.

Epoxy-carbon composites are a good example. This composite is well known in the automotive world for its use in Formula 1. Unfortunately, its high cost significantly limits its use in the general automotive world. Despite this, some car manufacturers have started to introduce carbon fibre in their vehicle designs. An example is the BMW i3 electric car, produced by the BMW Group since 2013. According to data from the SAMAR Institute, it is the most frequently purchased electric car in Poland [12].

A good example of the use of composites is found in fiberglass exterior panels for cars and trucks, and even for mass transit now. The German ICE4 or Polish Pendolino ED250 high-speed train uses composites in its modular nose cone. Using composites in the nose cone instead of steel reduces energy consumption because it reduces the vehicle

weight, improves train aerodynamics, and allows capacity to be increased. The outer composite shell of the driver's cab structure can also be manufactured in one piece, reducing manufacturing and assembly time. Additionally, the Siemens ICx train has recently highlighted several potential applications for composites, from drive components to couplers and service concepts. The energy absorber is made of glass fiber reinforced plastics (GFRP) that excel in longevity, offer constant energy absorption behavior, and have a weight one-third that of a standard steel absorber [13].

The case of the South Korean Tilting Train Express has a body made of composite panels with a sandwich-type structure. The sandwich design reduced the weight of the structure by 28% compared to a conventional steel-based design. [14,15,16].

A second possibility is to modify polymeric materials with carbon tubes or graphene [17,18,19]. Such a material will be an alternative to injection-moulded materials, which are currently modified with chopped glass fibre.

Materials modified with carbon nanoparticles are more mechanically robust, and the parts made of them absorb energy better. It is estimated that a car bumper made from such a modified material can absorb 40% more energy than a standard product [20, 21].

It appears that at the current stage of technological development, the use of carbon nanotubes is more economically beneficial than that of graphene. The technology for manufacturing nanotubes has been more mastered. Furthermore, nanotubes in combination with the polymer material make the material stiffer (Fig. 4), but also less brittle.

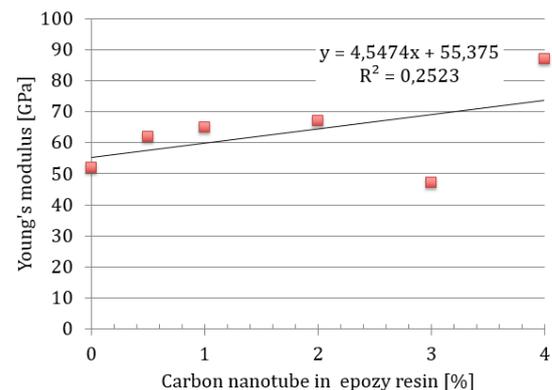


Fig. 4. Stiffness dependence of epoxy resin modified with carbon nanotubes, homogenisation time 2 min [own research]

The graph (Fig. 4) was created from bending strength tests on epoxy composite samples with 0.5, 1, 2, 3, and 4 %.

Multi-walled carbon nanotubes were fabricated in the Laboratory of Nanotechnology and Materials Technology using the CVD EasyTube ® 2000 System - First Nano (Fig 5).

The particles of the carbon nanotubes were dispersed in the epoxy resin system. The epoxy resin system was cured at ambient temperature with a hardener. We used epoxy resin Epidian 6 and hardener Z1 (mixed weight proportion 100:13), both by "Organika Sarzyna" Company (Poland). Epidian 6 is an epoxy resin obtained from bisphenol A and epichlorohydrin having an average molecular weight of 700. Z1 is triethylenetetramine hardener. Epoxy resin and Wood's alloy were mixed together at the ambient temperature (23°C) at the time of 5 minutes, the rotation speed was 10 000 rpm. Peripheral speed is: 13,09 m/s.

Mixtures were made to dissolver DISPERMAT LC30 by VMA-GETZMANN GMBH. Dissolver mixer fitted with a Zblade with 25 mm diameter of the disk. Mixing was done in a cylinder of 50 mm diameter. After the preparation, the compositions were cast in a mold of a size of 120x20x4 mm. In the next step, the samples were heated up in the dryer to 25°C. The Times of the samples curing was 24 hours.

Finally obtained samples of composites were bending tested using the Zwick/Roell Z020 testing machine. The crosshead speed of 5 mm/min was maintained throughout the test.

The mechanical properties of the composites were identified in the bending test.

Carbon nanotubes exhibit many very interesting and unusual properties, chemical and physical, due to their size (Fig. 5). However, for nanomaterials to be used increasingly in practice, efficient and cost-effective methods for their manufacture, and most importantly, suitable for industrial deployment, must be developed.

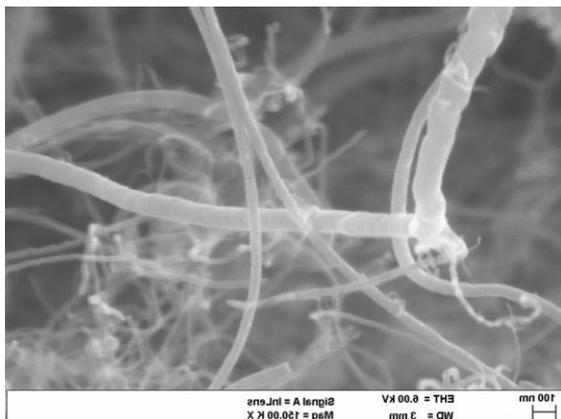


Fig. 5. Carbon nanotube cluster scanning microscope [own research]

Nanotubes can have a very wide range of applications. They are suitable as electrode materials for cells, as tactile sensors instead of membrane switches in car interiors, as energy storage. Composites containing them have better mechanical properties, high electrical conductivity and are also more resistant to various types of deformation, hence the interest in using carbon nanotube composites as a material for brake discs.

Composites of nanotubes with metals could be used to produce lighter and equally strong vehicle components such as engines. It is thought that nanotubes could improve the mechanical properties of car paintwork, making it more scratch-resistant while also having self-repairing properties. The use of nanotubes in vehicle glazing, on the other hand, could make it interactive and make it stronger, or impart anti-icing properties [22].

3. SUMMARY

The use of polymeric materials in the construction of modern motor vehicles is of great economic and technological importance. Their popularity is mainly due to their relatively low price, which provides an advantageous ratio of mechanical properties to density. New polymeric materials obtained by modification of both curable and thermoplastic materials will be a key element driving the development of the vehicle industry. At the same time, because it is based on known polymeric materials, it will be more of an evolution than a revolution. This direction of technological development favors economic solutions that are well-developed on the technological side. At the same time, better energy absorption by polymer materials leads to the production of much lighter and safer vehicles.

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