# ENVIRONMENTALLY FRIENDLY CAR PLASTICS IN AUTOMOTIVE ENGINEERING

**Part 1**

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## Summary

The possibilities to use polymer plastics in automotive engineering from the point of view of the manufacturing of an environmentally-friendly car have been presented in this paper. The general requirements to be met by such materials have been discussed and the possibilities of significant improvement of, inter alia, mechanical strength properties of polymer plastics by the use of appropriate additives, inclusive of carriers, have been indicated. The most frequently used plastics and numerous toughening materials have been mentioned. Many examples of the application of plastics toughened with the most recent materials, e.g. nanomaterials or, in consideration of the ecological aspect, natural fibres have been presented. The essence of the most modern technologies making it possible to manufacture vehicle components from plastics toughened with various carriers has also been described, which also covers the issue of hybrid structures.

Keywords: environmentally friendly car, toughened plastic and composite parts, toughening and reinforcing materials, toughened plastics and composite materials processing technologies, hybrid structures

## 1. Introduction

The energy security and environmental protection are crucial issues nowadays. From this point of view, it becomes a challenge to maintain mobility with simultaneously meeting the requirements of ecology. In these terms, an environmentally friendly car is defined as the one that should not burden the environment at any stage of its existence. This means that it should not cause any environmental degradation during the production, operation, and post-operation periods. Let us note, a car like this actually does not exist! The environmentally friendly car is a long-range goal of the automotive industry. The problems related to the manufacturing of such a vehicle may be solved by progress in the vehicle drive technology and development of the technologies that are aimed at a reduction of vehicle mass or resistance to motion or at a reduction of energy consumption during the vehicle production process. When the vehicle mass is reduced by 100 kg, the fuel consumption declines by 0.3 to 0.5 $dm^3$/100 km and the $CO_2$ emission decreases by 7.5 to 12.5 g/km [1]. According to some other sources, these benefits are estimated at 0.5 to 0.6 $dm^3$/100 km and even 13 g/km, respectively [2]. At present, most attention is paid to the emissions of harmful gases and dust.

The carbon dioxide emitted by automotive vehicles has been proclaimed a villain that causes all the "ecological misfortunes" and is responsible for global warming. Actually, the share of means of road transport in the total $CO_2$ emission is about 20%, with passenger cars being accountable for 12% [3]. Nevertheless, even this quantity provides sufficient grounds for the undertaking of all the possible steps to reduce the emission of greenhouse gases.

The use of plastics (in the broadest sense of this word) for the construction of vehicles will result in the following:

- Reduction in vehicle mass;
- Noise and vibration suppression;
- Improvement in passive safety;
- Reduction in manufacturing costs thanks to the application of innovative solutions, efficient technologies, and lightweight structures;
- Improvement in comfort and appearance of vehicle interior, due to decorative functions being also performed by plastic components (e.g. emblems, trademarks, ornamental strips, etc.).

Preferably, all these goals should be achieved simultaneously, thanks to which the car manufactured would be lighter, safer, more comfortable, more beautiful and, at the same time, less expensive. Although all these goals are extremely important, the reduction of mass and the suppression of noise and vibration should be considered the issues of top priority in terms of environmental protection.

The vehicle mass is effectively reduced by replacing metals with polymer materials, i.e. plastics. The use of such materials for the construction of vehicles means also considerable energy savings in comparison with the use of steel and aluminium because of the energy demand being lower during the vehicle production and operation period. Should the use of plastics in the construction of passenger cars be given up, the energy demand would rise by 26% [2]. Therefore, the use of plastics is indispensable, especially in consideration of the ongoing increase in the average mass of the European car. In 1985, the average car mass was 950 kg while now this figure reaches 1 200 kg [4]. A good example is Audi, whose mass grew by 460 kg for 30 years (from 1972 to 2003), in spite of plastics being used for the production of this car [5].

A precursor of the use of polymer materials for the production of passenger cars was Henry Ford, who applied plastics to his Ford-T model as early as in 1915 and who presented his "Hemp Car" with a body made of plastics reinforced with hemp fibre in 1941 [6, 7].

The first mass-produced car with its body made of plastics was Chevrolet Corvette of 1952 [8]; somewhat later, Trabant appeared in the then German Democratic Republic, with its sheathing being fully made of plastics (phenolic resin reinforced with nonwoven cotton fabric) [9].

At present, the share of plastics in the construction of vehicles averages out at 15 to 20%, by weight. As an example, the BMW 3 model being now manufactured consists of plastics in about 21% (for details see Fig. 1).

The quantities of plastic parts installed on the outside of a car, in the car interior, and in the engine compartment differ depending on car manufacturers and models; however, the general use of such materials, by weight and in percentage terms, could be summarised as shown in Fig. 2.

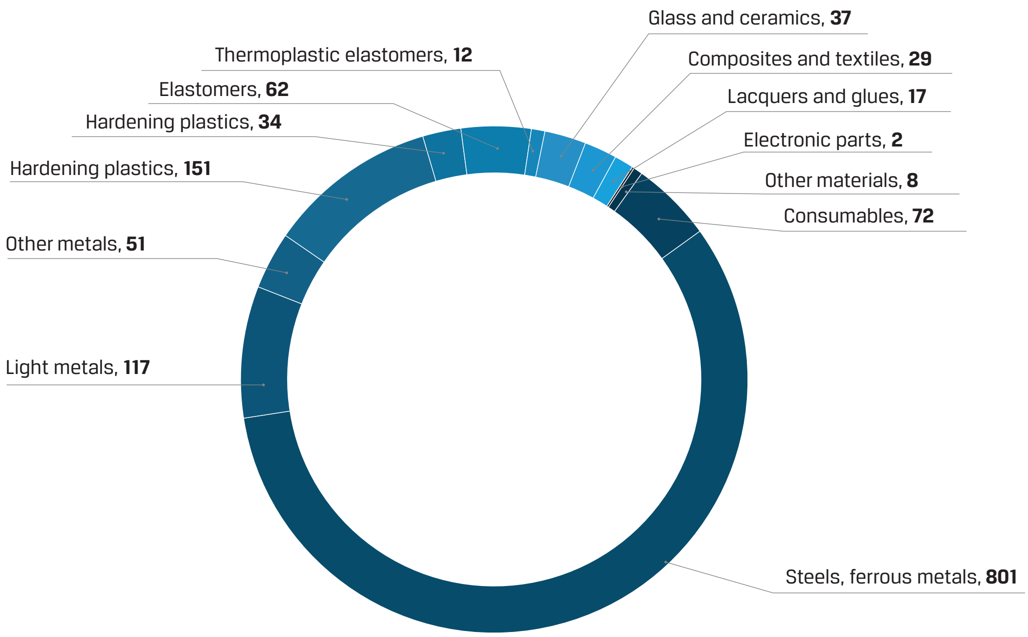


**Fig. 1. Share of individual material groups [kg] in the car mass, with the new BMW 3 taken as an example (Total car mass: 1 403 kg) [10].**

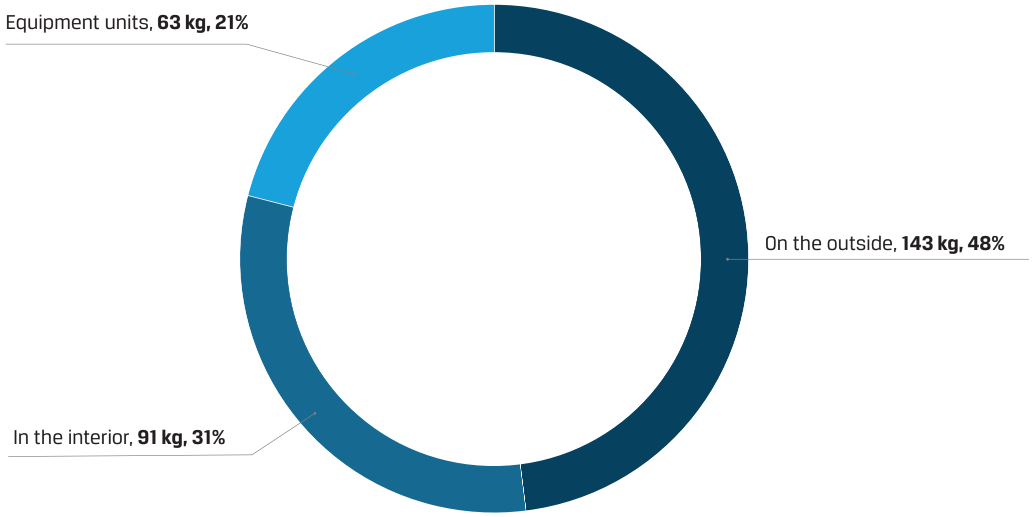


**Fig. 2. Use of plastics in the new BMW 3 [10].**

As it can be seen in the illustration, about 50% of the plastics used in passenger cars finds application on the outside of the vehicle, both in the vehicle body and in the chassis. The plastic parts include body components (e.g. sheathing panels or spoilers), fender liners, shields, and bumpers, as well as some components of the suspension system. In the interior, plastics are chiefly used to improve comfort (car upholstery, for better visual and tactile sensations) and to reduce noise.

The most spectacular plastics applications are polymer parts and fabricated components used to make vehicle "equipment units" (Fig. 2). We chiefly mean here the applications in the engine compartment, where the parts are exposed to heavy service conditions. Until recently, such conditions eliminated plastics from this area. Thanks to modern materials and manufacturing technologies, however, plastics applications of this kind are also continuously developing.

The said development of such plastics applications, forced by ecological and economic constraints, has been enabled, on the one hand, by development of polymer materials and plastics moulding technologies and on the other hand, by technological progress in the field of designing non-ferrous parts and assemblies and modern methods of testing the performance of such products. The role of vehicle assembling technologies in this development cannot be ignored, either.

## 2. Materials and technologies

Various polymer materials find application in the construction of vehicles. Apart from elastomers, which are not dealt with in this paper, both thermoplastics and hardening plastics are widely used. In these two groups, however, the share of homopolymers is gradually declining in favour of toughened plastics. The chemical industry intensively cooperates with car manufacturers, actively supporting the development work in the broadest sense of this word and offering materials according to the needs.

In automotive engineering, particular importance is attached to such plastics properties as mechanical strength, rigidity, thermal expansion, energy absorption capacity, resistance to elevated temperatures, insulation characteristics (noise suppression), and tribological properties. Moreover, polymer materials must show adequate chemical durability, depending on a specific application. In principle, only incombustible or slow-burning plastics are used in vehicle construction.

It is generally believed that metals show higher mechanical strength in comparison with that of plastics. When examining this issue a little bit more carefully, however, we can see that some mechanical properties of polymer materials may even be better than those of most metals are, depending on the toughening type and method applied. This is visually illustrated in Fig. 3. From the point of view of the application of polymer materials to the construction of automotive vehicles, a particularly interesting feature is the specific strength, i.e. the ratio of strength to specific weight ($\sigma_\gamma$), because this parameter determined for many plastics, especially toughened plastics, exceeds that of metals.

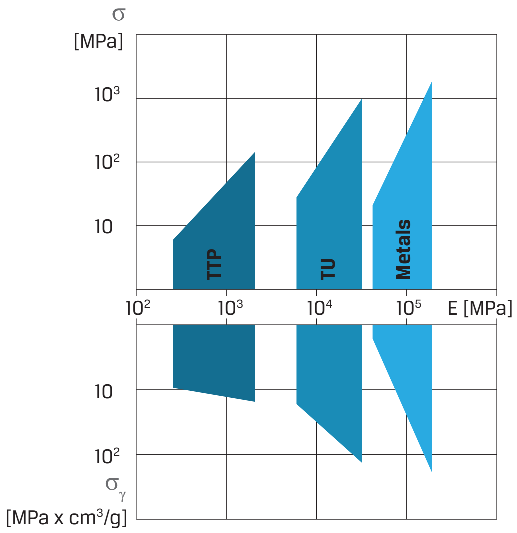


**Fig. 3. Comparison of some mechanical properties of plastics and metals (TTP = thermoplastics, TU = hardening plastics) [10].**

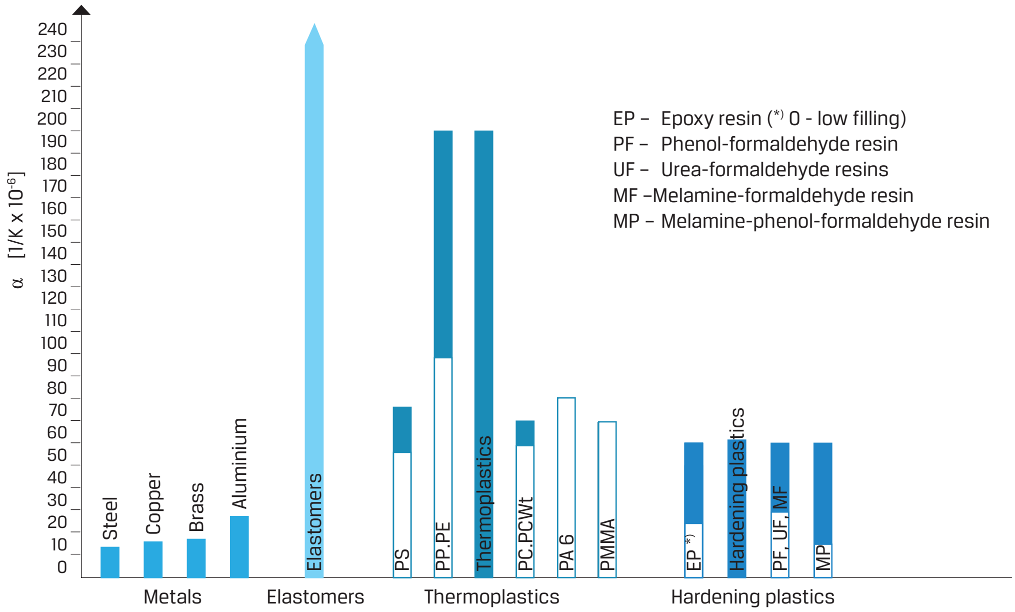


**Fig. 4. Coefficient of linear expansion of various materials [10].**

Another important feature of polymer materials that must definitely be taken into account at the vehicle designing stage is the linear thermal expansion (α). The comparison of the α coefficients for various materials as presented in Fig. 4 clearly shows that the linear expansion of plastics is, roughly, 10 times as high as that of metals. Simultaneously, there is a general rule that the more flexible (soft) plastic the higher its linear expansion α. As it will be shown in a subsequent part of this paper, the present-day material engineering technologies have successfully dealt with this troublesome problem as well.

One of the important requirements that must be met by the polymer materials used for automotive applications, especially by those to be located close to the engine, is adequate resistance to elevated temperatures. It is natural for plastics that their strength and rigidity decline with rising temperature of operation. At present, the chemical industry offers materials that may be operated at temperatures of up to 300°C. This is applicable to both thermoplastics (blue bars) and hardening plastics (green bars). For comparison, the temperatures of operation of conventional materials have also been shown. It can be seen that many polymer materials may be operated at higher temperatures than those acceptable for aluminium, which has been willingly used for the making of parts to be installed in the engine compartment but which requires particularly high energy consumption at the production process.

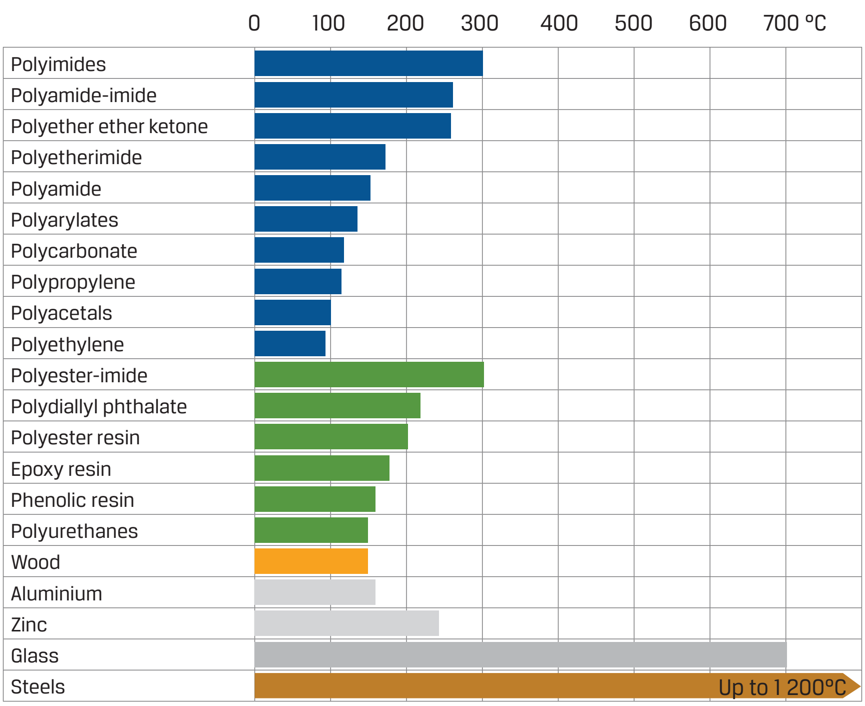


**Fig. 5. Operation temperature ranges for some polymer materials in comparison with those acceptable for traditional materials [11].**

Plastics are excellent sound insulating and deadening materials. In polymers, sound waves propagate much slower than they do in metals or glass. For plastics, the lower density and the lower elasticity, the higher acoustic wave absorption capacity. What is meant here is not exclusively the acoustic insulation (soundproofing) of a vehicle but also reduction of the noise emitted or transmitted by the vehicle parts themselves. The application of an oil sump made from appropriately toughened polyamide (PA66 GF35) to the Mercedes Actros vehicle has resulted in a reduction of the noise emitted by 2dB [11].

As already mentioned, the polymer properties described above are not permanently fixed at the time when these materials are produced: they depend on the filling and toughening additives applied, which are often referred to as "carriers," and the use of such additives depends on the service requirements of specific parts. The said additives, especially the toughening agents, significantly improve not only the mechanical properties but also the maximum acceptable temperature of operation. They also affect other characteristics of plastics, including thermal expansion. The fillers and/or toughening agents are added to the material before or in the course of material processing.

The carriers may be classified in different ways, depending on the criterion adopted. In the plastics processing, organic and inorganic materials of natural origin become increasingly popular as the carriers. Jute, sisal, hemp, and other fibres do not significantly raise the strength and Young's modulus of the material but they may meet specific strength and durability requirements of some parts; simultaneously, they are favourably perceived because of ecological considerations. The use of natural fibres to reinforce automotive parts made from polypropylene (PP) may be illustrated by the following examples:
- Rear shelf and door trim panel in the VW Beetle: curaua leaf fibre [12];
- Spare wheel well in the Merceds A: abaca leaf fibre [13];
- Door, floor, etc. soundproofing and insulating parts in the Mercedes E: 43 kg of wool, hemp, and sisal fibres [14].

Plastics of very high strength may also be made with the use of an inorganic nanomaterial, i.e. montmorillonite[1], of natural origin as well.

Synthetic materials make a definitely larger group of the carriers. This group also includes both organic and inorganic materials. Examples of the former may be directed polyethylene fibres (high crystalline linear PE) or aramid fibres while the latter may be represented by various forms of glass carriers and special mineral carriers (such as wollastonite, i.e. calcium metasilicate of acicular structure).

By form, the following reinforcements may be distinguished:
- Particles and dispersions, e.g. powders, microspheres, flakes, etc.;
- Fibres, rowing (strands of continuous monofilaments connected together in parallel), wires, whiskers (monocrystalline fibres of metals, metal oxides, metal nitrides, silicon carbide, boron carbide, graphite, etc.), nanotubes, and the like;
- Flat, e.g. mats, fabrics, tapes, etc.;
- Three-dimensional or stranded structures of various kinds.

[1] http://www.freidok.uni-freiburg.de/volltexte/7773/

Most of them were, or still are, in use as toughening additives to the plastics intended for automotive applications. In recent years, nanomaterials have been gradually introduced as additives to polymer materials to reinforce automotive parts or to give them special properties. In most cases, the montmorillonite mentioned above is used, which is predominantly applied as a toughening agent to polyamides (PA). The toughened polyamide is a material used to make cylinder head covers, camshaft drive toothed belt covers, or fuel system components; polypropylene thus reinforced is used to make dashboards with increased resistance to scratching, dirt, etc.

A high degree of reinforcement is achieved by the application of fibres arranged in the polymer matrix in the direction of loads, which makes the material highly anisotropic. In most cases, staple fibre is used for this purpose, which may be explained, *inter alia*, by relatively well-mastered processing techniques. The staple fibre is the most popular material used to reinforce the parts made from thermoplastics. Parts reinforced with short glass fibres of the "E" type[2] have been installed in automotive vehicles for many years. Now, plastics reinforced with carbon fibre become increasingly popular, in spite of the constraints caused by high material and process costs. The prognoses in this field are very good because such parts are light and tough. In comparison with parts made of steel or aluminium, they are lighter by 60% and 25%, respectively. At the same time, they show high fatigue strength and good appearance, without the need to apply any additional coatings. The parts made from toughened plastics are characterised by high stability of shape. Even in short-run production, the tooling costs are low because high durability of moulds is not required. The possible applications of the materials in question include the hybridisation of structural parts and assemblies as well as the load-bearing structures and complete vehicle bodies [15].

Even better effect of directional reinforcement is achieved by the introduction of long fibres to the polymer matrix. The technique of making materials thus reinforced, known in the case of parts and products based on hardening resins, has only been recently mastered for thermoplastics [16]. Predominantly, polyamides (PA66, PA6) are involved here; however, the toughening method like this is also applied to other thermoplastics, such as polypropylene or polybutylene terephthalate (PBT); it is used as well to reinforce parts made from polyacetals (POM). By press moulding of long fibre thermoplastics (LFT), chassis components and load-bearing structures to fix radiators, headlamps, etc., are made.

The continuous fibres (especially glass fibre) combined with polyester resins or epoxy resins, used for a long time, give the highest directional reinforcement. Thus, some reinforcing longitudinal structural components, but also tanks (made by winding), are manufactured. Continuous fibres were also used to make leaf springs, as presented in a subsequent part of this paper.

Very good isotropic reinforcement effects are obtained by using mats or woven or knitted fabrics of any kind, made of glass, carbon, aramid, or other fibres. In the Volkswagen vehicles, the bottom shield of the engine compartment is made from thermoplastics reinforced with glass mat [17]. The materials of this kind are sometimes referred to as "organic sheets."

[2] The "E" mark of the glass fibre of this type is derived from the fact that this fibre was originally used in electrotechnology. This fibre is made of pure quartz with calcium, kaolin, and orthoboric acid used as additives. It is the cheapest and most frequently used glass fibre.

The most frequently used thermoplastics that are converted in toughened form into vehicle parts are polyamides, especially PA66 reinforced with glass fibre (GF), with the share of fibres reaching even 60%, as it is in the case of the spare wheel well in the Audi A8 [18]. Important features of this material are high strength and rigidity, good vibration suppression, and raised thermal resistance. The PA66 reinforced with glass fibre is used to make inlet manifolds for the BMW and Porsche cars (GF30 and GF35, respectively) [19, 20]; with 15% of a mineral filler added to it, this material is used to make cylinder heads for the VW Passat and Audi A4 (GF25) [21]. The PA66 GF35 is also used in many other vehicle assemblies, e.g. transmission system, air springs (the MAN truck), oil sumps, etc. [11, 21, 22].

In automotive engineering, polyamides are also used in the form of mixtures with other thermoplastics. A material thus improved is a mixture consisting of polyamide and polyphenylene ether (PA+PPE). This material is characterised by considerably higher thermal resistance and raised thermal stability of shape and dimensions. Progress in the material research work carried out in common by the chemical and automotive industries have resulted in the development of special polyamides suitable for the making of vehicle body components. The processes of painting with the use of the KTL method[3] (with drying at a temperature of up to 200°C) do not affect the shape and dimension stability of the parts [23].

The reinforced polyamides, like other thermoplastics, are moulded in principle with the use of conventional methods. The difference in comparison with non-toughened thermoplastics lies in the method of introduction of the toughening agent to the material. In the case of reinforcing with staple fibre (0.3÷10 mm long), three methods are used:

1. The mixing of the polymer material with the staple fibre takes place in the plasticising unit of the injection moulding machine. The moulding process roughly corresponds to the technology of injection of non-toughened materials.

2. The polymer material is mixed in the course of a separate process with the reinforcing fibre with the use of compounders, where the fibre is introduced into the base polymer material mainly in the form of rowing or having been cut. Thanks to this, a material with relatively long fibres may be obtained and, in consequence, shapes of high strength may be moulded.

3. In result of continuous impregnation of a strand of the reinforcing fibre with molten polyamide (the "pultrusion" method) and cutting of the product, a granulated material with glass or carbonised fibres introduced into it is obtained. The fibres are arranged in parallel and the fibre length corresponds to the granule size (6÷10 mm). The granulated material is further processed with the use of the injection technology.

Polyamides or other thermoplastics, e.g. polypropylene or polyethylene terephthalate (PET), reinforced with long fibres (about 25 mm), require the application of quite different technologies. In this case, the IMC[4] method, which is also used for shorter fibres, is applied. It incorporates two processing methods, i.e. a continuous compounding process and a cyclic

[3] KTL is the German abbreviation for cathodic dip painting.
[4] Injection Moulding Compounder

process of injection moulding. As an example, the IMC technology is used to make front panels for the Citröen C3, Peugeot 307, Audi A3, and VW Golf and Bora cars [24].

Another technology of making structural vehicle components of plastics reinforced with long fibres in the form of rowing is connected with the use of a process line consisting of compounder (a device that prepares the material and additives to processing), extruder, and high-speed press, as shown in Fig. 6.

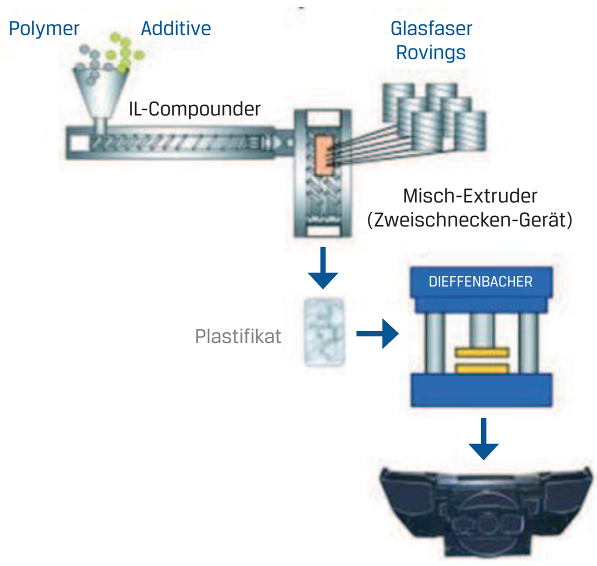


**Fig. 6. A technology of moulding vehicle components from plastics reinforced with long fibres [25].**

To make vehicle body sheathing components from thermoplastics reinforced with continuous fibre, press moulding techniques are also used. In this case, the reinforcing fibres are formed into structures prepared with the use of textile techniques (woven or knitted fabrics). Thus, *inter alia*, the so-called "organic sheets" are made, which are finally shaped by moulding in a pressing tool. Another method of making vehicle body components is the polymerisation of a material (e.g. cast polyamide) in a mould filled with carrier consisting of continuous fibres [26].

Polyurethanes (PUR) make one more group of plastics commonly used for the construction of vehicles. Depending on the moulding technology and modification method adopted (the use of fillers or staple or continuous reinforcing fibres), parts of extremely wide range of properties are made from such materials. On the one hand, foamed polyurethanes show significant energy absorption and vibration suppression capability and, therefore, they are willingly used to make bumpers or insulation and soundproofing materials and parts. On the other hand, these materials in solid form are resistant to high temperatures and are suitable for painting with the use of the KTL method. They show high impact resistance in low temperatures and their low thermal expansion (for PUR reinforced with wollastonite or carbon fibre, $\alpha < 40\times10^{-6}$ 1/K or $\alpha < 25\times10^{-6}$ 1/K, respectively) enables the maintaining of small gaps ("zero-gap appearance") and perfect fit, at adequate dimension stability. Thanks to low water absorbability, this material is suitable for use in warm and damp climate. Therefore, it is used to make body components, bumper shields, fender sheathing, rocker mouldings, door panels, side panels, strips, and spoilers [27].

To shape the parts made from polyurethane reinforced with fibre, low pressure injection techniques, such as R-RIM (Reinforced Reaction Injection Moulding), are used. This technology consists in the mixing of reagents (polyol and isocyanate) and reinforcing fibres and the injection of the mixture into a closed mould. After the reaction is completed (the material has been solidified), the finished shape is removed from the mould.

In the automotive vehicles manufactured at present, numerous examples of application of parts made from polymer composites can be noticed. They are chiefly external sheathing elements and shapes made of composites reinforced with glass or carbon. In most cases, polyester resins (UP) and epoxy resins (EP) are the base material. Less frequently, other materials are also used [28]. Well thought-out reinforcement of the structure makes it possible to direct the fibres so that they are subjected to tension during operation. Continuous carbon fibres show very high tensile strength, reaching 1 900 MPa. Examples of composite structures used in automotive vehicles have been shown in a subsequent part of this paper.

To toughen hardening materials, carriers in various forms are also used. In most cases, the parts made from thermosetting plastics are moulded from compounds obtained with the use of the BMC (Bulk Moulding Compounds) technology and containing toughening agents in the form of staple glass fibre or other reinforcing materials. Even large-size shapes, e.g. rear window frames, are made for the automotive industry by injection moulding or press moulding.

The best-known method of making plastic parts reinforced with continuous fibre, although not very popular in the automotive industry, is the one referred to as "pultrusion."[5] This method is used to make reinforcing beams used in the construction of vehicles and spring leaves [29]. At present, the latter are more frequently made from pre-impregnated tapes.

Sheathing components made from polyester or epoxy composites reinforced with mat or cloth layers are low-pressure moulded. The process is carried out with the use of the vacuum bag method, in autoclaves, or by the RTM (Resin Transfer Moulding) vacuum injection method. In the RTM method, metered resin is introduced into the mould to impregnate the reinforcing layers appropriately arranged there and the excess resin is carried away by means of a vacuum applied. The product is moulded in a press or a similarly functioning device.

Sheathing components of vehicles of lower or medium class are more frequently made from polyester composites reinforced with glass fibre. For sports cars or cars of higher quality class, epoxy-glass or epoxy-carbon composites are used, depending on specific requirements.

Hardening plastics may also be used in combination with other polymer materials.

[5] Pultrusion is a continuous profile production technique where a strand of reinforcing fibres is impregnated with resins and pulled through a die appropriately shaped.

An interesting example of such a solution is the cab roof in the MAN truck series, consisting of external modified epoxy layer, insulating and soundproofing layer of foamed PUR, and epoxy-glass laminate (a mat layer). The whole structure is made in a three-stage process with the use of the RTM method [30]. Epoxy composites reinforced with continuous carbon fibre in combination with duralumin pipe are used to manufacture gasholders. Trial hydrogen holders have already been made from modified polyurethane and epoxy resin-based composite with anisotropic reinforcement made by winding continuous carbon fibres [31].

The lot industrial production is based on pre-impregnated materials or intermediate products made with the use of the SMC (Sheet Moulding Compounds) method. Depending on design requirements, intermediate products with reinforcing staple fibre arranged at random (SMC-R), directed staple fibre (SMC-D), or unidirectional continuous fibre (SMC-C) are used. The successive versions of the pre-impregnated materials show increasing strength and E modulus. The reinforced materials with variously arranged pieces of carbon or aramid fibre, mats, or woven fabrics with required orientation and weave are generally available and willingly used. Such pre-impregnated materials are ready for further processing; having been cut to the required profile and placed in the mould, they are hardened in the moulding process at appropriate process parameters (temperature and pressure).

For several years, hybrid structures being combinations of a metal part with plastic have been used in the construction of automotive vehicles. The metal part is formed in most cases by plastic working and placed in a seat of the mould into which thermoplastic material is then injected. This technology, based on the effect of synergy of properties of the materials used, results in a reduction of the mass of the vehicle components thus made with their strength and rigidity being raised at the same time. As a rule, the manufacturing costs are simultaneously cut down and the vehicle designers are given more freedom in the shaping of the vehicle body.

In hybrid structures, the metal parts are chiefly combined with polyamides (PA6, PA66) reinforced in most cases with short glass fibre (30÷35%) [e.g. 32]. In some designs, long fibre or continuous fibre is used to reinforce the structure [33], which may be illustrated e.g. by the propylene front panel in the Mercedes Vito/Viano NCV2 vehicles.

To manufacture the hybrid structures, methods having been well known and used for many years as well as some others being less popular are applied. The methods used at present are predominantly based on the injection technology (where the metal component is seated in the injection mould). The following techniques of the manufacturing of hybrid structures are known:

1) "Insert moulding," where metal inserts covered with the plastic injected perform functions additional to those of the plastic;

2) "Outsert moulding," where the plastic is injected as an additional material and the functional part has the form of a slide bearing, latch, sleeve, etc.;

3) PMA (plastic metal assembly), where the injected structure is integrated with a finished metal part in an assembly operation by means of latches, rivet-like plastic "buttons", etc., injected simultaneously;

4) MOM (metal over moulding), where plastic is injected to metal parts seated in the mould to form a finished structure with plastic reinforcement and, in most cases, other components connecting both materials together;

5) Metal-Gaim (metal-gas assisted injection moulding);

6) Metal-Waim (metal-water assisted injection moulding).

The essence of the last two techniques of manufacturing of hybrid structures also lies in the injection of a polymer material into a mould with a metal component seated in it, but the liquid core of the structure is removed by gas or water at increased pressure (the Metal-Gaim or Metal-Waim process, respectively), thanks to which the product interior is left empty [34, 35].

This technology is successfully applied to the manufacturing of front panel, boot lid, and other structural vehicle parts. In series production, the hybrid front panel was applied for the first time to the Ford Focus.

A significant improvement of mechanical properties is obtained in result of the use of a method referred to as "hybrid plus," where an appropriate primer is applied to steel sheet which is then subjected to conventional stamping. Afterwards, fibre-reinforced polypropylene ribbing is formed on the stampings by spraying. Finally, the parts may be subjected to dip painting (KTL) [36].

## 3. Concluding considerations

The increasingly stringent environmental and economic requirements determine the directions of development of materials, designs, and technologies used at the production of vehicles. This also concerns the application of plastics, especially those additionally toughened, in the automotive industry. It is already now forecasted, in a more optimistic version, that the vehicle mass may be reduced in the near future by about 50%, on average. For vehicles with conventional drive systems, the main goal is still a reduction of vehicle mass, or at least keeping of the mass on a stable level in spite of a growth in the quantity of additional vehicle equipment and accessories.

This generates at present an increase in innovativeness in the field of the application of polymer materials and new technologies of production of such materials as well as new vehicle engineering solutions. The cooperation of the automotive industry with material manufacturers and research and development institutions is also continuously intensified. The still existing constraints in the wide application of polymer materials in the construction of automotive vehicles, such as high material and process costs (manufacturing times, instrumentation, and tooling), will induce optimisation of material properties and manufacturing processes.

As regards materials, trends are emerging towards the wider application of modern toughened plastics such as:

- Nanocomposites;
- Composites reinforced with carbon fibre;
- Biopolymer composites ("green polymers"), reinforced with nanotubes, carbon fibres, or natural fibres;
- Thermoplastic multi-material composites or systems, e.g. laminated composite reinforced with nanotubes;
- High-quality recyclates;
- Modern films and coating materials.

The techniques of preparation of pre-impregnated materials will further develop, in particular in the field of forms of the reinforcements of various kinds. Plaited, embroidered, and sewed parts will find industrial applications.

By optimisation of materials (e.g. by shortening of the resin reaction times or by improvement of material processability) and by process automation to eliminate the manual processing methods to a significant extent, the production times will be shortened, thanks to which the production costs will be cut down and new mass production applications will be made possible. For some composite parts made with the use of the RTM technology, the production time has already now been reduced from 20 min. to 2÷4 min., with the heat soaking process having been eliminated at the same time.

In result of the use of appropriate additives, the coefficient of linear expansion will be further improved, to an anticipated level of $(4÷5)×10^{-5}$ $K^{-1}$, and the thermal stability of parts will be raised. Thanks to this, further constraints in the wide application of plastics in automotive engineering will be eliminated.

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