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POLYMERIC MATERIALS IN AUTOMOBILES

ABSTRACT

Polymeric materials in automobiles have experienced a real boom in the last twenty years, and their application is increasing with a tendency of further growth. The basic functions of such wide application of polymeric materials in vehicles dictate the appearance of the automobiles, their functionality, economy and low fuel consumption. The application of polymeric materials allows more freedom in design, and in many cases only the polymeric materials can enable safe geometrical or economical solutions for the design parts.

KEY WORDS

polymeric materials, functionality, economy

1. INTRODUCTION

The application of polymeric materials in automobiles is constantly increasing and this trend is expected to continue. The key factors in selecting the polymeric materials in relation to other materials applied in automobiles are the today's appearance of automobiles, their functionality and more economic manufacture, as well as reduced fuel consumption. Although the reduction of the mass of parts is the main reason of choosing polymeric materials, the future growth of their usage will result in new applications in automobiles related to comfort, safety and possibility of parts integration. The application of polymeric materials allows more freedom in design, and in many cases only these materials can allow safe geometrical or economic solution for the construction of parts.

The automobile parts which are made of polymeric materials are divided into four categories: internal parts, external parts, parts in the engine compartment, and bodywork and engine parts.

2. KINDS AND TYPES OF POLYMERIC MATERIALS FOR THE MANUFACTURE OF AUTOMOTIVE PARTS

2.1. Polycarbonate (PC)

Polycarbonates are often used for the application in automotive industry. They are applied mainly in non-reinforced condition, and their main application in automobiles is for the manufacture of various parts of light assemblies, such as lights and lenses of the front and rear lights.

It features the following properties [6]:

- resistant to high temperatures (up to 148°C), whereas high-temperature polycarbonate (PC-HT) is resistant to temperatures (from 160-220 °C);
- transparent with possibility of being painted into any nuance;
- modulus in tension up to 2300 MPa;
- high dimensional stability, precision and good properties of toughness;
- good electric insulation properties.

2.2. Acrylonitrile/butadiene/styrene (ABS)

Primarily used for the manufacture of housings, covers and linings, featuring the following properties [6]:

- very good properties of toughness, strength and rigidity;
- they are opaque, attain high surface polish i. e. have well polished surface;
- good chemical resistance and resistance to temperature of 80-105°C;
- modulus in tension is from 1500-2700 MPa, and when fibre glass reinforced even up to 5500 MPa.

2.3. Thermoplastic alloy

For the manufacture of automobile parts often thermoplastic alloy polycarbonate+acrylonitrile/butadiene/styrene (PC+ABS) is used, and the thermoplastic alloy acrylonitrile/butadiene/styrene+polyamide (ABS+PA). The alloys allow combining of mechanical, thermal and rheological properties of materials. The thermoplastic alloy of polycarbonate+ +acrylonitrile/butadiene/styrene (PC+ABS) is used to manufacture the internal and external decorative parts and small bodywork parts, and features the following properties [6]

- it is opaque, has high surface polish;
- resistance to temperature between ABS and PC;
- high dimension stability and reaches high precision in the production of small parts;
- slight tendency to distortion and humidity absorption;
- features good electric insulation properties;
- modulus in tension from 1800-2750 MPa, and fibre glass reinforced 3900-5900 MPa.

Thermoplastic alloy acrylonitrile/butadiene/styrene+polyamide (ABS+PA) is used for the manufacture of unpainted parts in the car interior, such as: housings for radios and navigation systems, sliding roof supports, air nozzles and air conditioning grates, gear level linings, steering wheels, etc., and also for the manufacture of painted external parts: hub covers, grilles and fenders.

Compared to acrylonitrile/butadiene/styrene graft copolymer(ABS) has enhanced properties of chemical resistance, resistance to crack occurrence due to the action of residual stresses, greater dynamic load power. Compared to polyamide (PA), thermoplastic alloy (ABS+PA) features better properties of machinability, lower tendency to shrinkage and deformation and lower water absorption. Thermoplastic alloy (ABS+PA) features great flexural and notched impact strength as well as good chemical resistance. The temperature resistance is up to 180°C if based on polyamide (PA6), and up to 250°C if based on polyamide (PA66) [6].

2.4. Polyamide (PA)

Most often used are polyamide 66 (PA66) and polyamide 6 (PA6). The main application of polyamide is the manufacture of parts which are under the engine hood, mainly using the types of polyamide (PA) reinforced by fibreglass.

Polyamide 66 features the following properties [6]:

- it is opaque and features good rigidity and hardness;
- high resistance to temperature (in short-term exposure up to 250°C, in long-term exposure from 80°-150°C), and resistance to many chemicals;
- features very high strength and toughness (depending on the modifications, reinforcements and humidity);
- modulus in tension of 900-15000 MPa (depending on the modifications, reinforcements and humidity);
- features good electric insulation properties and very good resistance to wear and tear.

Polyamide 6 features the following properties [6]:

- it is opaque, features good rigidity and hardness, it is resistant to many chemicals;
- features good electric insulation properties and very good resistance to wear and tear;
- it features very high dynamic strength and toughness, depending on modifications, reinforcements and humidity;
- features high resistance to temperature (in short-term exposure up to 200°C, and in long-term exposure from 80°-150°C);
- modulus in tension ranges from 450-15000 MPa.

2.5. Linear polyester

For the application in automotive industry the linear polyester is also applied, such as the linear polyesters based on polybutylene-terephthalate (PBT) and polyester (PES). In the majority of cases the fibreglass reinforced types are applied. They are used for the manufacture of bumpers, door-handles, body plates, radiator grilles, rear-view mirror housings, etc. and feature the following properties [6]:

- high resistance to temperature (short-term exposure from 210° - 240° C);
- high strength and hardness, good chemical resistance, and they are opaque;
- excellent sliding properties, good electric insulation properties;
- high resistance to abrasion and low absorption of humidity;
- modulus in tension ranges from 1700-17000 MPa depending on modifications.

2.6. Urethane elastomere (TPE-U)

These polymeric materials combine the properties of high-quality polyurethane with processing efficiency of thermoplastics. The most important application of urethane elastomeres is for the body parts and steering wheel, and they feature the following properties [6]:

- good resistance to oils and greases, good resistance to chemicals;

- good at absorbing impacts and vibrations, they feature good recovery after deformation;
- good resistance to formation and propagation of cracks;
- resistance to temperatures from – 40°C - 80°C (in short-term exposure up to 12°C).

2.7. Polyvinyl chloride (PVC)

This is a material used in automotive industry for the manufacture of the protection for the bottom floor in the car, for internal lining and coating of electric cables in the vehicle, and features the following properties [17];

- low thermal resistance at high temperatures;
- good absorbent of impacts and vibrations, low flammability;
- diversity of manufacturing procedures, easy to weld, paste, and print.

3. SYSTEMATIZATION OF AUTOMOTIVE PARTS

3.1. Internal parts of automobile

In the passenger cabin, polypropylene (PP) has been increasingly used to manufacture the parts, and its share has reached 55%. The use of fabric in the car interior for the seats, roof linings and side-plate linings, will be increasingly replaced by and made of polypropylene (PP).

An example is the new design of the seat shell in Mercedes Benz A-Class, made of fibreglass reinforced elastomere modified polyamide (PA6). The seat shell is equally safe as the one made of metal, but has lower mass.

The first car that had installed the back seat bank of metal/polymers was Mercedes Benz V-Class van. The goals of the project were comfort, seat-belt integration and adaptability. The seat can be turned, pulled backwards, reclined in order to save space or converted into a flat table. The mass is 36 kg, the seat has 30-50% lower mass than the traditional ones, and the saving in price is from 10-20%.

An example is the recently developed prototype of the dashboard support in the plastic/metal hybrid technology. The polymeric material that was used for this prototype is the fibreglass reinforced polyamide. The transfer from the metal assembly of pedals to those made of polymeric materials means that the mass, strength, price and characteristic of new parts have been significantly improved. By cooperation among several companies, an assembly of pedals made of polymeric materials was designed, and in 1999 these were installed in the Ford models. The new design of pedal assembly reduces the assembly mass by 50% and the number of parts by 50%.

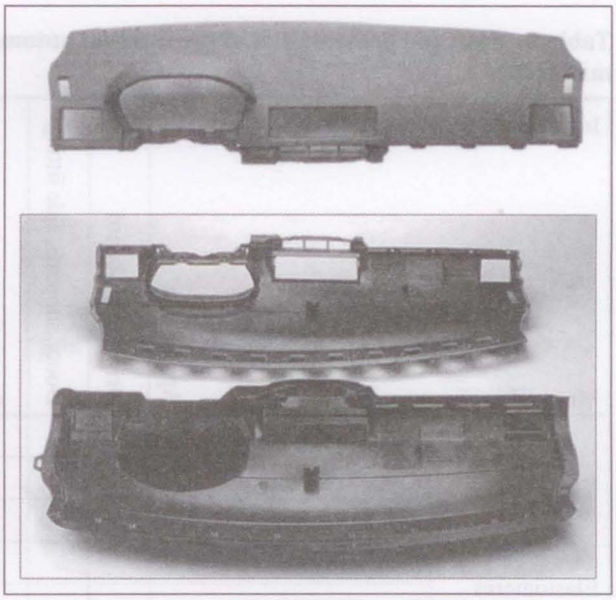

Figure 1 - Driver's dashboard in Skoda Fabia

The driver's dashboard of Skoda Fabia, in spite of having thin walls, with large-size parts made of long-fibre reinforced thermoplastic Celstran (LFT) is extremely rigid and tough and its mass has been reduced as well as the fuel consumption. Made of 30% fibreglass reinforced polypropylene (PP GF30), it features invisible integration of airbags which have been tested and found to function well even at extremely low temperatures (up to –35°C) [11].

The passenger safety requirements have become an indispensable part in forming the interior of cars, searching for materials that increase these requirements and offer the desired level of comfort. The roof linings of VW (Volkswagen) make, are made of a system of polyurethane rigid foam, and they offer very good combination of comfort and safety, have very low mass, look very attractive and absorb well the impacts. An example for the new trend in the design of the interior parts is the integrated door mechanism assembly. It is made of thermoplastic alloy polycarbonate+acrylonitrile/butadiene/styrene (PC+ABS) mixture of resins which allow high level of functional integration and lower production costs, lower mass and simpler mounting.

3.2. External automobile parts

The application of polymeric materials on the outside of an automobile may be roughly classified in three main areas of application [9]:

- large-size body parts (external door panels, rear hatch, engine cover, bumpers, mudguards, spoilers, bonnet lids, etc.),

Table 1 - Systemic presentation of the internal automobile parts and polymeric materials of which they are made [10]

Materials	Internal parts / Application	Driver's dashboard	Doors, supports, side fittings	Supports	Seats	Convertible top covers	Steering wheels	Heating/air conditioning	Lights/fuses	Floor lining, bonnet lining	Pedals	Machine elements	Door unit	Bonnet
Elastomeres	Perbunan (NBR)											■		
	Krynac (NBR)											■		
	Therban (HNBR)							■	■			■		
	Levapren (EVM)								■	■				
	Buna EP(EPDM)								■	■	■	■		
	Silopren (MVQ)	■	■					■	■			■		
	Baymod (NBR)	■	■	■										
	Baymoflex (ASA+ANM)	■	■	■										
Thermoplastics	Lustran/Novodur (ABS)	■	■	■	■		■	■	■			■		
	Bayblend (PC+ABS)	■	■	■	■	■		■	■			■	■	■
	Cadon (SMA+ABS)	■												
	Centrex (ASA)	■												
	Triax (ABS+PA)	■	■	■										
	Makrolon/Apec (PC)	■				■			■					
	Durethan (PA)	■	■		■		■	■			■	■	■	
	Pocan (PBT)	■	■					■				■		
	Desmopan (TPE-U)	■		■	■				■			■		
	Makrofol (PC film)	■		■										
Polyurethanes	Polyurethane (PUR)	■	■	■	■	■	■	■	■	■		■	■	■

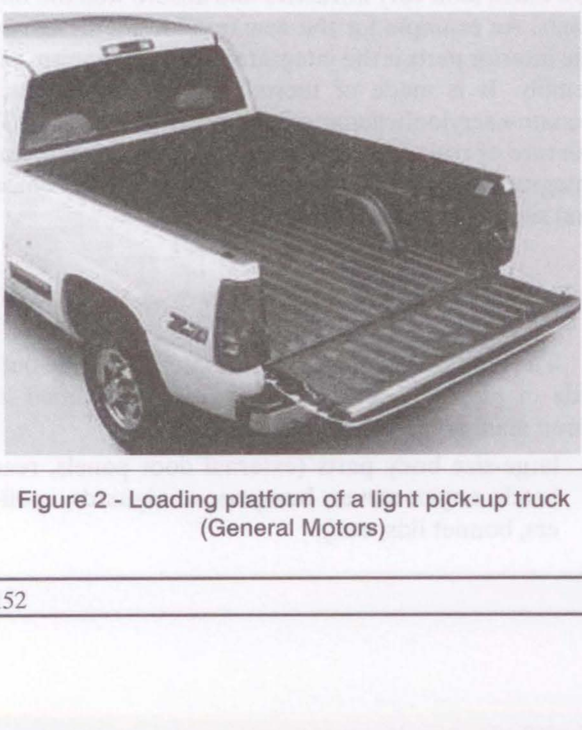

Figure 2 - Loading platform of a light pick-up truck (General Motors)

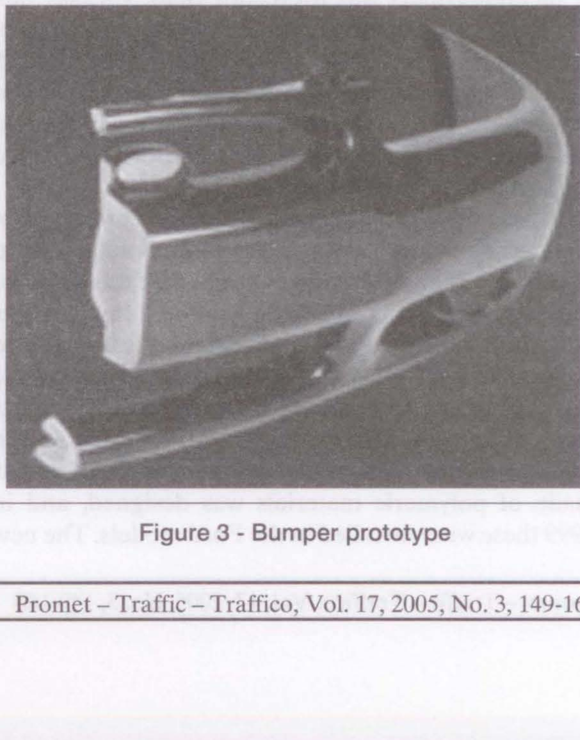

Figure 3 - Bumper prototype

Table 2 - Systemic presentation of external automobile parts and polymeric materials of which they are made [10]

External parts / Materials	Application	Bumpers	Front transversal support	Grilles	Rear-view mirrors	Handles and locks	Sliding roofs (tops)	Bodywork parts	Glass sealants	Side panels	Wheel covers
Elastomeres	Baypren (CR)										
	Bayer Butyl (IIR)					■	■	■			■
	Bayer Bromobutyl (BIIR)					■	■	■			■
	Bayer Chlorobutyl (CIIR)					■	■	■			
	Perbunan (NBR)					■					
	Krynac (NBR)					■					
	Therban (HNBR)					■					
	Levapren (EVM)										
	Buna EP (EPDM)	■				■	■				
	Krylene (SBR)										
	Krynol (SBR)										
Thermoplastics	Lustran/Novodur (ABS)			■	■						■
	Bayblend (PC+ABS)			■	■	■	■	■			■
	Centrex (ASA)			■	■						
	Triax (ABS+PA)			■							
	Makrolon/Apec (PC)	■									
	Durethan (PA)	■	■	■	■	■	■	■			■
	Pocan (PBT)	■	■	■	■	■	■	■			
	Desmopan (TPE-U)							■			
	Makrofol (PC film)			■			■				■
Polyurethanes	Polyurethane (PUR)	■	■	■	■		■	■	■	■	

- small-size body parts,
- instruments for lighting and light signalisation and glazed body surfaces (rear light covers, headlight optical lenses, etc.).

Large-size body parts

General Motors is leading in the world in using the bodywork panels made of polymeric composites that are based on thermoset plastics. They have been using them since 1953 for the Corvette whose bodywork is made of fibreglass. The first reaction injection moulded (RIM) polyurethane bumper lining was used for Chevrolet Monza in 1975. In 1980 the rear door (hatch) was made for the first time in Oldsmobile caravan of sheet moulding compound (SMC). This development has brought to the use of a wide range of thermoset composites for the engine lids, roofs (tops), lid edges, mudguards, door panels, and other bodywork panels, in the following processing methods: sheet moulding compound (SMC), bulk moulding compound (BMC), (RRIM and SRIM) reinforced reaction injection moulding, (RTM) resin transfer moulding. The first loading platform of the light pick-up truck Chevy Silverado (General Motors) (Figure 2) was made of fibreglass reinforced polyurethane Baydur. The external panels and the external rear door, whereas the internal panel is of a single part, are made by reinforced reaction injection moulding

Table 2 (continued) - Systemic presentation of the external automobile parts and polymeric materials of which they are made [10]

External parts / Materials	Application	Front lights	Rear lights	Wipers	Glazed surfaces	Accessories	Bumper shock-absorber	Bottom protection floor	Floor assembly	Seals	Loading platform of a light pick-up truck
Elastomeres	Baypren (CR)			■							
	Bayer Butyl (IIR)	■	■		■		■				
	Bayer Bromobutyl (BIIR)	■	■		■		■				
	Bayer Chlorobutyl (CIIR)	■	■		■		■				
	Perbunan (NBR)						■			■	
	Krynac (NBR)						■			■	
	Therban (HNBR)						■				
	Levapren (EVM)							■			
	Buna EP (EPDM)									■	
	Krylene (SBR)									■	
	Krynol (SBR)									■	
Thermoplastics	Lustran/Novodur (ABS)		■			■					
	Bayblend (PC+ABS)		■			■					
	Centrex (ASA)		■								
	Triax (ABS+PA)										
	Makrolon/Apec (PC)	■	■		■	■					
	Durethan (PA)	■	■	■		■					
	Pocan (PBT)	■		■							
	Desmopan (TPE-U)		■				■	■		■	
	Makrofol (PC film)					■					
Polyurethanes	Polyurethane (PUR)				■	■	■		■	■	■

(SRIM). The advantages include significantly reduced mass, high strength, resistance to very high, as well as very low temperatures and the wall thickness of only 3 mm [10].

An inventive concept of a bumper prototype (Figure 3) made of polyurethane should allow better protection of pedestrians in case of accident. Thanks to the combination of two different types of Bayer polyurethanes, the pedestrian injuries in case of accident can be significantly reduced. This has been achieved by fibre reinforced surfaces of PUR whose thickness is only 1.5 mm, in the back filled with energy absorbing semi-rigid polyurethane (PUR) foam. The bumper surface is made of reinforced reaction injection moulding (RRIM) thin-wall technique [12].

An interesting concept is featured by the prototype of the automobile called CCV (Composite Concept Vehicle), Chrysler Corp. The CCV bodywork consists of only four large-format panels made of glass filled linear polyester (PET). Two outer panels and two inner panels are adhesion-joined along the car symmetry, which are then built onto the bodywork of high-strength steel using only four screws.

Small-size bodywork parts are mainly made of acrylonitrile/styrene/acrylate graft copolymer (ASA), thermoplastic alloy acrylonitrile/styrene/acrylate+ +polycarbonate (ASA+PC) compound, polyamide (PA), thermoplastic alloy acrylonitrile/styrene/acrylate+polycarbonate (PP), thermoplastic alloy polycarbonate+acrylonitrile/butadiene/styrene (ABS+PC)

Table 3 - Systemic presentation of engine compartment parts and polymeric materials of which they are made [10]

Engine compartment parts / Materials	Application	Driving belts	Intake manifolds	Seals, membranes	Valve lids	Noise dampers	Fan housing	Fuel ducts	Air ducts
Elastomeres	Baypren (CR)	■							■
	Bayer Butyl (IIR)					■			
	Bayer Bromobutyl (BIIR)					■			
	Bayer Chlorobutyl (CIIR)					■			
	Perbunan (NBR)			■				■	■
	Krynac (NBR)			■				■	■
	Therban (HNBR)	■		■				■	■
	Levapren (EVM)			■	■				■
	Buna EP (EPDM)			■		■			■
	Krylene (SBR)			■					
	Krynol (SBR)			■					
	Silopren (MVQ)			■	■		■		■
Thermoplastics	Lustran/Novodur (ABS)								■
	Makrolon/Apec (PC)								
	Durethan (PA)		■		■	■	■	■	■
	Pocan (PBT)								■
	Desmopan (TPE-U)			■					■
Polyurethanes	Polyurethane (PUR)	■				■	■		■

compound and acrylonitrile/butadiene/styrene graft copolymer (ABS). This application includes rear-view mirrors, internal protection mudguard linings, radiator grilles, door handles, housings and covers of wipers, lights.

One of the latest developments in the field of lighting instruments and lighting signalisation are the optical lenses of the front headlights made of polycarbonate (PC). They are much lighter and more resistant to fracture than classical ones, and they allow greater freedom in design. The surface is coated by a protective layer thus increasing the resistance to scratches.

3.3. Engine compartment parts

The development of technology, improvements in the resistance to temperature and resistance to the media has enabled major application of polymers in this highly demanding automotive design sector. Individual parts are being increasingly combined into assemblies. A good example of parts integration is the air supply system. Such a system for the BMW series of Diesel engines integrates a number of parts into a single assembly: the intake manifold, cylinder head lid, air filter housing, recirculation system of exhaust gases with valve and oil filtering system. All these parts are made of polyamide (PA6 and PA66) [15].

The most important polymeric materials in application for the engine parts are the polyamides. Various types of polyamides are used (e. g. PA6, PA66, PA11 and PA12), and in the majority of cases they are fibreglass reinforced. Among other thermoplastics, mainly poly(oxymethylene) (POM), poly(phenylene-sulphide) (PPS) and poly(buthylene-terephthalate) (PBT) are used.

Table 3 (continued) - Systemic presentation of engine compartment parts and polymeric materials of which they are made [10]

Engine compartment parts / Materials	Application	Oil ducts	Water mains	Heating, ventilation and air-conditioning	Covers	Parts of electr. systems	Flanges, dust protectors	Engine lid
Elastomeres	Baypren (CR)	■	■	■			■	
	Bayer Butyl (IIR)			■				
	Bayer Bromobutyl (BIIR)			■				
	Bayer Chlorobutyl (CIIR)			■				
	Perbunan (NBR)	■	■	■			■	
	Krynac (NBR)	■	■	■			■	
	Therban (HNBR)	■	■	■		■	■	
	Levapren (EVM)	■	■	■		■	■	
	Buna EP (EPDM)		■			■		
	Krylene (SBR)		■	■				
	Krynol (SBR)		■	■				
	Silopren (MVQ)	■	■	■		■	■	
Thermoplastics	Lustran/Novodur (ABS)			■	■			
	Makrolon/Apec (PC)					■		
	Durethan (PA)	■	■	■	■	■		■
	Pocan (PBT)					■		
	Desmopan (TPE-U)					■	■	
Polyurethanes	Polyurethane (PUR)	■		■	■	■	■	

According to some estimates 80% of all intake manifolds produced in Europe are made of thermoplastics. The first intake manifold was made of 30% fibreglass reinforced polyamide, for Mercedes Benz cars for E-Class automobiles [10].

3.4. Parts of bodywork and engine

The most important application of polymeric materials in this area is the manufacture of fuel tanks. The material used to manufacture fuel tanks is high-density polyethylene (PE-HD).

Fuel tank made of polymeric materials was a pioneer project of the BASF. Made by blow moulding of high-density polyethylene (PE-HD) of high-molecular mass, it offered several advantages [4]:
- seamless tank;
- good mechanical properties;
- high shaping flexibility.

Compared to polymeric tanks, the metal tank has 10÷11 kg greater mass and does not feature considerable freedom in design. Today, multi-layer blown fuel tanks are manufactured in five or six layers.

A significant contribution in designing structural parts of the bodywork is the application of the so-called hybrid technology, which allows manufacture of low mass structural parts using polymer/metal composites. This concept combines polymers of small mass (glass reinforced PP or glass reinforced PA) with structural integrity of metal [9].

A good example is the new front transversal support of Ford Focus (Figure 4), whose serial production has already started. The concept combines two processes: *deep drawing* of metal, of thickness of only 0.5 mm, and *injection moulding* of polymers (30% fibreglass reinforced PA6).

Table 4 - Systemic presentation of structure parts and body and the polymeric materials of which they are made [10]

Design parts and body / Materials	Application	Steering wheel, body and suspension system	Shock-absorbing instruments	Braking system	Pneumatics	Friction linings
Elastomeres	Baypren (CR)	■	■	■		
	Polysar (SBR)				■	
	Perbunan (NBR)	■		■		■
	Therban (HNBR)	■	■	■		
	Buna EP (EPDM)	■		■		
	Buna CB (BR)				■	
	Buna SL (SBR)				■	
	Krylene (SBR)	■		■	■	■
Polyurethanes	Durethan (PA)	■		■		
	Pocan (PBT)	■		■		
	Desmopan (TPE-U)	■	■			
Polyurethanes	Polyurethane (PUR)	■	■			

Figure 4 - Front transversal support, Ford Focus [14]

4. MANUFACTURING PROCEDURES OF AUTOMOTIVE PARTS MADE OF POLYMERIC MATERIALS

4.1. Injection moulding

Injection moulding is the most important cyclic procedure of processing polymers and it is the most widely applied procedure in manufacturing automobile parts.

Injection moulding of polymers is a cyclic procedure of shaping by injecting the polymeric substance of a required shear viscosity from the preparation units into the temperature regulated mould cavity. By polyreaction and/or crosslinking or cooling the product, the mould part becomes suitable for demoulding [16].

The injection moulding procedure can be automated and it is suitable for manufacturing moulded parts of high dimensional stability and complexity, as well as of different sizes. Injection moulding can be applied for low-viscous liquids (e.g. integral-polyurethane foams) or polymeric melts (e. g. thermoplastic melts).

Before, the main principle of injection was piston injection, and today it is injection moulding with screw. The material enters a heated melting cylinder through a funnel, where it is caught by the screw. The material melts, and gathers at the top of the screw. When enough molten material is collected, the whole screw moves forwards and injects the melt through a nozzle into the mould feed system. At the beginning of cooling the material contracts, and the melt continues to remain under post-pressure. Later, the screw returns into the initial position and prepares for the new quantity of material, and the mould opens and the product is demoulded [16].

The injection moulding machines contain only one screw, and big injection moulding machines can inject up to 175 litres of melt at a time.

Successful development of injection moulding of thermosets has significantly expanded their field of application. The injection moulding of thermosets is especially competitive in the production of thick-wall moulding parts, due to the much shorter cycle duration. For injection moulding of thermoset melts a machine can be used which is also used for injection moulding of thermoplastics.

Elastomeres can also be injection moulded, and elasto-thermoplastics are injection moulded in compliance with the rules of injection moulding of thermoplastics.

4.2. Blow moulding

Blow moulding is a cyclic procedure of forming a preform into a product, hollow body which strengthens its shape by cooling.

Blow moulding is a very important processing procedure, meant for production of hollow articles or one-side open hollow bodies. In the first phase of the production of hollow bodies by blow moulding a preform is produced by extrusion or injection moulding. In the second phase the workpiece is shaped. According to the method of producing the preform the extrusion blow moulding and injection blow moulding are distinguished [16].

Extrusion blow moulding is most often used for the production of items of many thermoplastics such as polyolefins (PP, PE), acrylonitrile/butadiene/styrene graft copolymer (ABS), rigid and flexible poly(vinyl-chloride) (PVC), polyamide (PA) etc. The products can be axis-symmetrical, but also of irregular shape (e. g. fuel tanks in automobiles).

The semi-product of the first phase of extrusion blow moulding, preform, is obtained from the extruder in the form of a flexible pipe (hose). A part of the pipe is then enveloped in a mould made of light metal because of efficient heat supply. The mould is closed and in the process one end of the pipe, usually the bottom, is squeezed by the mould and welded. The other end of the pipe is cut off and the blow moulding machine is inserted in it. By pressing the blow moulding machine, the neck of the future product is formed. Compressed air is then blown through the blow moulding machine, which widens the pipe and pushes it to the mould wall [16].

Injection blow moulding also consists of two work phases. In the first, the preform is made by injection blow moulding, after completed pressing the moulded part remains on the core and is transferred usually by turning the core, into the mould for blow moulding. Compressed air is then blown through the blow moulding machine core and the product continues to be shaped as described for extrusion blow moulding. However, unlike extrusion blow moulding, the products of injection blow moulding feature higher quality surfaces since there are no welded edges and consequently no flash or waste material either.

4.3. Heat forming

The films, foils or plates cut from extruded or calendered strips are used as preforms for heat forming. The preforms are also made by direct and indirect pressing, casting and compression forming of polypropylene. Many thermoplastics are suitable for heat forming.

In order to be formed, the preform must be in rubber state. Therefore sometimes the still non-cooled strip is conducted directly to the forming machine, but more often the preform must be heated, usually by exposing it to infrared beams or by contact with heated part of the machine [16].

Out of the heat forming procedures stretching is most widely used, that can be caused by mechanical compression, air pressure or sub-pressure action, and combination thereof. The most frequent are the following forming procedures by stretching [16]:

- free stamp forming, unheated preform is formed freely (i. e. without matrix) by pressing the heated stamp,
- forming by compressed air, the heated preform is printed by compressed air into the matrix,
- free forming by compressed air,
- forming in the matrix with sub-pressure, the preform is drawn into the matrix due to the sub-pressure in it,
- forming in the matrix with stamp and sub-pressure, the preform is stamp printed into the matrix from which the air is drawn out, and the preform clings closely to the matrix,
- forming on stamp with sub-pressure, the preform is stretched by stamp in which there is sub-pressure, and it clings along the stamp and acquires its shape.

4.4. Extrusion

Extrusion is the most widely used processing procedure of polymeric materials. Extrusion is used to produce the so-called continuous products or semi-products (extrudates), i. e. such products whose dimensions are not all final nor precisely defined (such as e. g. rigid and flexible pipes, sticks, coated cables).

Extrusion is a procedure of continuous primary shaping, by pressing the liquefied polymers through nozzles. The extruded polymer hardens in the product, extrudate by cooling, crosslinking or polymerisation. Extrudate is stacked or winded. The cyclic piston pressing is called extrusion. The thermosets and thermoplastic poly(tetraphluorethylene) are extruded [16].

The basic elements of extrusion line are the extruder (machine) and the mould. The extruder serves to press the liquefied thermoplastic obtained by softening or solving. It is pressed by worm rolls, screws or plates. The most frequent are the single-worm extruders, but the extruders with several worms are also used.

Solid polymer in the form of granules or powder enters the extruder through a funnel. The entry of polymer is often enhanced by pre-pressure or sub-pressure. The elastomeres usually enter the extruder in the form of strips. The polymer falls into the cylinder and then it is caught by the rotating worm screw and pressed towards the extruder head. During the process the polymer is compressed, its volume is reduced, and it is also heated. If the heating of polymer caused by friction is not sufficient, the extruder cylinder is heated on the outside by the electro-resistant band heaters. By passing through the cylinder the softened polymer can be very well mixed, and thermally and mechanically homogenized [16].

5. CONCLUSION

In the last thirty years the polymeric materials have become reliable materials in the design of automobiles. The use of polymeric materials is constantly increasing and this trend is expected to continue. Whereas some thirty years ago, the average share of polymeric materials amounted to only 6% of the overall mass of middle class automobiles, today this share exceeds 13%.

The most important reasons for applying polymeric materials compared to other materials are:

- low mass structures;
- comfort;
- safety;
- savings, i. e. lower production costs;
- greater freedom in design;
- and integration of parts.

Although reduction of the mass of parts is the main reason for selecting polymeric materials, the future growth in the usage of polymeric materials will lead to new applications in automobile related to comfort, safety and especially the possibility of integrating parts.

The work provides a systematization of the main automotive assemblies that are made of polymeric materials, and gives certain concrete examples of application. Automobile parts that are made of polymeric materials have been classified in four main categories.

- *internal parts;*
- *external parts;*
  - large-size bodywork,
  - small-size bodywork parts,
  - lighting instruments and light signalization and glazed bodywork surfaces.
- *parts in the engine compartment,*
- *bodywork and engine parts.*

Polymeric materials are very easily shaped into the necessary forms, their surface is smooth eliminating the need for further machining, they are chemically resistant eliminating the need for surface protection, they are lighter than metal and glass and good insulators. All this makes the experts and designers more interested in the study of the widespread use of these materials in the future of the automotive industry.

6. USED ACRONYMS AND ABBREVIATIONS

ABS – acrylonitrile/butadiene/styrene
ABS+PA – thermoplastic alloy acrylonitrile/butadiene/styrene+polyamide
ASA – acrylonitrile/styrene/acrylate
ASA+PC – thermoplastic alloy acrylonitrile/ /styrene/acrylate+polycarbonate
BMC – bulk moulding compound
LFT – long fibre reinforced thermoplastic
PA 11 – polyamide 11
PA 12 – polyamide 12
PA 46 – polyamide 4.6
PA 610 – polyamide 6.10
PA 6-3-T – amorphous polyamide
PA 66 – polyamide 6.6
PA6 – polyamide 6
PBT – poly(butylene-terephthalate)
PBT+PET – thermoplastic alloy poly(butylene- -terephthalate)+poly(ethylene- -terephthalate)
PC – polycarbonate

PC+ABS – thermoplastic alloy polycarbonate + +acrylonitrile/butadiene/styrene
PC+PBT – thermoplastic alloy polycarbonate+ +poly(butylene-terephthalate)
PDAP – poly(diallyl-phthalate) resin
PEEK – poly(ether-ether-ketone)
PE-HD – high density polyethylene
PE-LD – low density polyethylene
PET – poly(ethylene-terephthalate)
PF – phenol-formaldehyde resin
PMMA – poly(methyl-methacrylate)
POM – poly(oxymethylene)
PP – polypropylene
PP GF30 – 30% fibreglass reinforced polypropylene
PPE (PPO) – poly(phenylene-ether) [poly(phenylene oxide)]
PPO+PA – thermoplastic alloy poly(phenylene oxide)+polyamide
PPS – poly(phenylene-sulfide)
PS – polystyrene
PTFE – poly(tetrafluoroethylene)
PUR – polyurethane
PVC – poly(vinyl-chloride)
RIM – reaction injection moulding
RRIM – reinforced reaction injection moulding
RTM – resin transfer moulding
SMC – sheet moulding compound
SRIM – reinforced reaction injection moulding
SUI – internal combustion engines
TPE-U – thermoplastic elastomere
PES – polyester

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SAŽETAK

POLIMERNI MATERIJALI U AUTOMOBILIMA

Polimerni materijali u automobilima doživjeli su pravi procvat u proteklih dvadesetak godina, njihova primjena je u porastu sa tendencijama danjeg rasta. Temeljne funkcije tako velike primjene polimernih materijala u vozilima diktiraju izgled automobila, funkcionalnost, ekonomičnost te mala potrošnja goriva. Primjena polimernih materijala omogućuje više slobode pri konstruiranju, a u mnogim slučajevima samo polimerni materijali mogu omogućiti sigurna geometrijska ili ekonomična rješenja za konstrukcijske dijelove.

KLJUČNE RIJEČI

polimerni materijali, funkcionalnost, ekonomičnost

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