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Research Article

RESEARCH OF COMPOSITE MATERIALS USED IN THE CONSTRUCTION OF VEHICLE BODYWORK

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ABSTRACT

Contemporary vehicles have an increasing number of bodywork elements made of composites. Their advantages are undoubtedly weight reduction and increased corrosion resistance. On the other hand, accidental repairs are becoming difficult, however, in case of minor deformation there is often no permanent deformation. The authors researched the issue of the strength of composite bodyworks varies over time and in case of minor accidental damage, qualifying the element for further use. The paper presents the results of research on the structure and strength of composite body elements of selected vehicles. Undamaged components and plating parts that were damaged in collisions were examined.

Keywords: vehicle bodywork, composite, strength.

INTRODUCTION

People have been using motor vehicles for more than 100 years [20]. During this time, vehicles have undergone enormous technical and technological changes, their purpose and utility functions have also changed. Internal combustion engines and their accessories, as well as transmission units had underwent major changes. The biggest changes were, however, in the production of vehicle bodyworks and the materials used for their construction. In order to improve transport safety and environmental protection, the efficiency and reliability of vehicle safety systems has been systematically increasing and more and better elements [3] and construction materials are being used. Limiting the negative impact of vehicles on the natural environment at the stage of operation largely depends on the structural design (using modern propulsion units, combustion and neutralization systems for harmful chemical and energy emissions) [15].

The automotive industry uses a variety of technologies to produce components and assemblies. Parts of engines such as crankshafts, connecting rods, valve levers, pistons, etc. are manufactured by plastic processing. Thanks to this technology, the advantageous arrangement of the fibers in the material is obtained, so that they have high strength properties. In addition to conventional plastic processing methods, for example die forging, new methods of manufacturing parts such as flange molding in hollow products [11, 24] are sought. In the production of passenger cars, the bodywork occupies an average of approximately 60% of the production area of the plant. The machine park is very expensive, because it consists of large presses with pressures up to 2000 t. For composite components, special technological machines are required for their production, which further raises production costs. With production of more than an average of more than 50,000 units a year in a car every 2 to 4 minutes, it is profitable to automate press processes consisting of a total of several hundred units with different pressures and table surfaces [17].

Due to the increasing demands of the population for driving comfort, safety, and the need for additional equipment to achieve the desired emissions, vehicle weight is growing disproportionately. Today's cars are, therefore, an average of 200 kg heavier than the same category of vehicles manufactured 25 years ago. The growing weight of the vehicle has a direct impact on fuel consumption, and the only solution is the use of new lightweight materials with properties consistent with the steel used so far. In the manufacture of bodywork, special high strength steels are used on key bodywork sites, leading to substantial savings and vehicle weight reduction. Vehicle weight reduction and noise as well as vibration damping are achieved primarily through innovative construction and material solutions, in particular using reinforced plastics [1]. The results obtained by Duflou et all [6] reveal the need for a differentiated attitude towards more intensive use of composites in automotive design. In an effort to achieve a major weight reduction, the use of composites is currently intensively explored, with carbon fibre reinforced polymers (CFRPs) perceived as a promising alternative for steel and non-ferro structures [4, 6, 16]. In a number of recent research projects, technological aspects of the use of CFRPs for structural car body construction have been studied [22, 23]. Properly selected processing conditions make it possible to manufacture products with new, modified physical and technological properties [9]. Determining the properties of polymeric materials is the subject of much research, as evidenced by the following work [2, 8, 10, 12, 13, 16, 25].

Due to the improved impact performance characteristics, composites are widely used in engineering and military applications to absorb the impact energy. [8]. Composites as energy absorber, light-weight and anti-corrosion materials are the perfect substitutions for metallic structure specifically in the case of impact [2]. Although these materials have not the possibility for plastic deformation due to their brittle nature, they have high stiffness and strength-to-weight ratios [2]. Several works have been done on investigating the energy absorption and crashworthiness of composite. Mamalis et al. [14] studied the collapse modes of sandwich panels made of composite face-sheets and a foam core under axial compression force. Three collapse modes were observed. The first collapse mode occurred with foam core shear failure and sandwich fragmentation. The second mode was characterized by face-sheets delamination and buckling and the third one was the progressive crushing mode. It was proved that the third mode is the most important type of sandwich collapse mode due to energy absorption capacity of the structure, it depends on the foam core properties [2].

Composites used to build a car body consist of two components. The first of these components is a warp, which is responsible for giving a sufficiently high hardness, but also for the proportion of elasticity of the material, and the second component is the structural material (reinforcing material) responsible for strengthening the composite. The main task of the warp is to protect the construction material and to transfer stresses from external loads when the main role of the composite reinforcement material is to provide high mechanical properties. The use of polymer composites ensures the highest level of structural reliability, but at the same time it entails the highest cost of car body parts.

In addition to the numerous advantages of polymer composites, they have physical defects (changes in strength properties even in a small temperature range, greater susceptibility to impact damage) and technological ones, among others, way of designing composite elements connections [25]. However, as these authors add, despite these drawbacks, composite materials, especially polymer-glass and polymer-carbon laminates, are widely used not only in sports cars (such as Sterling RX, Ferrari 458, Lotus Elise 72 JPS) or racing (eg. McLaren MP4-1, McLaren F1), but also in commercial vehicles (eg. Daimler Smart, Audi A8) [4, 25]. Plastic materials have a long history of use in the automotive industry. Henry Ford, who used them at Ford T in 1915, was the precursor to the use of plastics in the car. In 1952 the Chevrolet Corvette was launched, [26] followed by the German DKW and Trabant [18], with a body made of plastic (duroplast). Duroplast car body has increased crushing strength, in case of fire duroplast is not burning and its melting point is similar to the melting point of aluminum. The breakthrough technologies of the Renault brand with lightweight vehicles [5] and the Renault Espase car produced since 1984. The exceptionally smooth body panels are made of a preimpregnated glass fibre: sheet moulding compound (SMC) [7, 19].

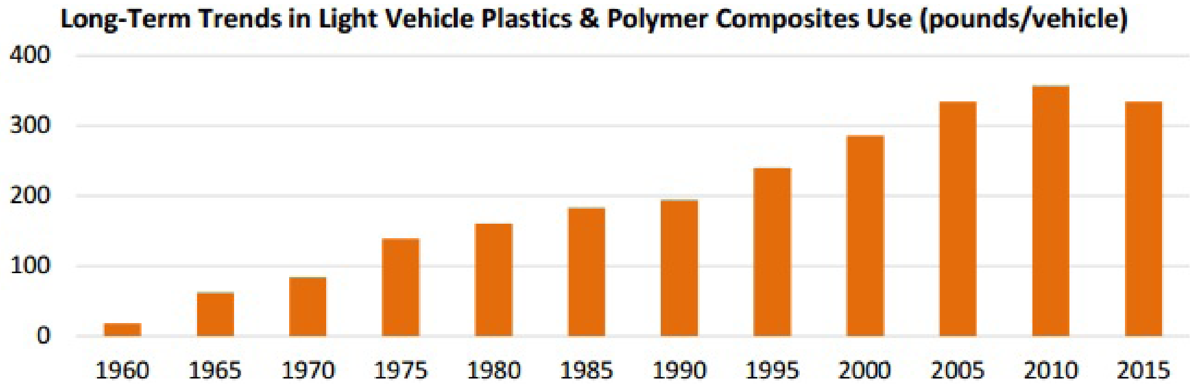

Fig. 1. The tendency of using light materials in vehicle construction [28]

Light vehicles represent an important market for plastics and polymer composites, one that has grown significantly during the last five decades. Figure 1 shows the long-term trends in light vehicle plastics and polymer composites use. The average light vehicle now contains 334 pounds of plastics and polymer composites, 8.4% of the total weight but approximately 50% of total vehicle volume [28]. This is down from 359 pounds in 2010, but up from 286 pounds in 2000 and 194 pounds in 1990. In 1960, less than 20 pounds were used [28]. It is estimated that without plastics, today's cars would be at least 200kg heavier, resulting in increased fuel consumption [30]. As previously mentioned, it is estimated that 100 kg of plastics have replaced between 200 and 300 kg of conventional materials in the modern car [30]. This weight saving is estimated to reduce fuel consumption by 750 liters over a life span of 150,000 km. All things being equal, further calculations suggest that, in total, this saves the cost of oil by 12 million tonnes and CO2 emissions by 30 million tonnes per year in Western Europe [30].

In Table 1 are shown plastics used in a typical passanger car.

Although up to 13 different polymers may be used in a single car model (Tab. 1), just three types of plastics make up some 66% of the total plastics used in a car: polypropylene PP (32%), polyurethane PUR (17%) and poly-vinyl-chloride PVC (16%) [21].

From ecological point of view, the possibility of reuse of construction materials in vehicle construction is very important. Hence, the increasing share of vehicles is recycled. Chrysler uses recycled polyurethane foam plastic in the seat cushions of its Jeep Grand Cherokee, and the wheel liners on the Jeep Wrangler and Chrysler 200 are made with 64% recycled plastics [29]. In 2013, nearly 40% of the thermoplastics (the most widely used types of plastics in autos) in Chrysler's European vehicles were recycled plastics [29]. GM uses air deflectors (used to direct air flow) for its Volt made from plastic caps, bottles, and other recycled materials. The company also uses plastic caps and shipping aids from its Fort Wayne facility to make radiator shrouds (used to protect the radiator) for the Chevrolet Silverado and GMC Sierra pickups built at that facility [29].

Ford uses recycled plastics to create upholstery for passenger seat cushions in numerous

Table 1. Plastics materials used in a typical passenger car [30]

Part	Main types of plastics	Weight in av. car (kg)
Bumpers	PP, ABS, PC	10.3
Seating	PUR, PP, PVC, ABS, PA	13.0
Dashboard	PP, ABS, PA, PC, PE	7.0
Fuel systems	PE, POM, PA, PP	6.0
Body (incl. panels)	PP, PPE, UP	6.0
Under-bonnet components	PA, PP, PBT	9.0
Interior trim	PP, ABS, PET, POM, PVC	20.0
Electrical components	PP, PE, PBT, PA, PVC	7.0
Exterior trim	ABS, PA, PBT, ASA, PP	4.0
Lighting	PP, PC, ABS, PMMA, UP	5.0
Upholstery	PVC, PUR, PP, PE	8.0
Liquid reservoirs	PP, PE, PA	1.0
Total		105.0

models. For example, the seat fabric for each Focus is made with approximately 22 plastic water bottles [29]. Ford also collects damaged bumpers but Honda recycles scrap bumpers generated during the manufacturing process to make plastic materials for replacement bumpers. Manufacturers such as Toyota and Nissan do the same and also use recyclable materials. Nissan uses plastic fibers made from used bottles as the main component in sound insulation layers in dashboards [29]. The automaker also uses plastics recycled from bumpers to create new bumpers, as well as plastics recycled from bottle caps to make new auto parts [29]. Toyota recently announced that 20% of the plastics used in its vehicles are made with recycled plastics or derived from plant materials [29].

The paper presents the results of structure and strength tests of composite elements of plating of selected vehicles. The tests were subjected to undamaged elements and coming from the plating parts, which have been damaged during a traffic collision.

MATERIALS AND TEST PROCEDURE

Selected components of plating made of composite materials derived from passenger cars had been tested. The first out of tested elements was the front fender of the Renault Clio II in 2003, made of polyamide (PPE-PA66) without reinforcement (color red samples). The second test item was a front fender from the 1983 Trabant, made of duroplast (blue samples). The third test piece was the right front door of the Renault Espace III (dark green samples). The car components from which samples were taken are shown in Figure 2. Renault Espace has all engine parts despite the bonnet made of glass polymer composite. These elements are mounted on a framework of galvanized steel. These vehicles are characterized by very high corrosion resistance. Despite the large cabinets and 7 people in the interior has a low weight, about 1.5t.

The material samples obtained from the car body were subjected to tensile tests using a static tensile test on the ZD-40 endurance machine. The obtained results and the dimensions, and cross-section of the samples are shown in Table 2. All samples were obtained in a non-varying material structure, and the arrangement of the fibers of the material had no effect on the resulting results (the arrangement of fibers in the material was accidental).

Fig. 2. The vehicle body elements used in the tests

TEST RESULTS

Figure 3 shows the samples after the strength test for the polyamide PPE-PA66. As you can see in Figure 3, the samples in 3 cases cracked at the jaws of the device, while in case of two samples – in the middle. In case of lacquer coating it was noted that the lacquer was cracked laterally at the stretching which means that the material is more elastic than it.

Figure 4 shows vehicle components made of duroplast after a strength test.

As shown in Figure 4, there are fragile fractures, one at the jaw, the other between the jaws.

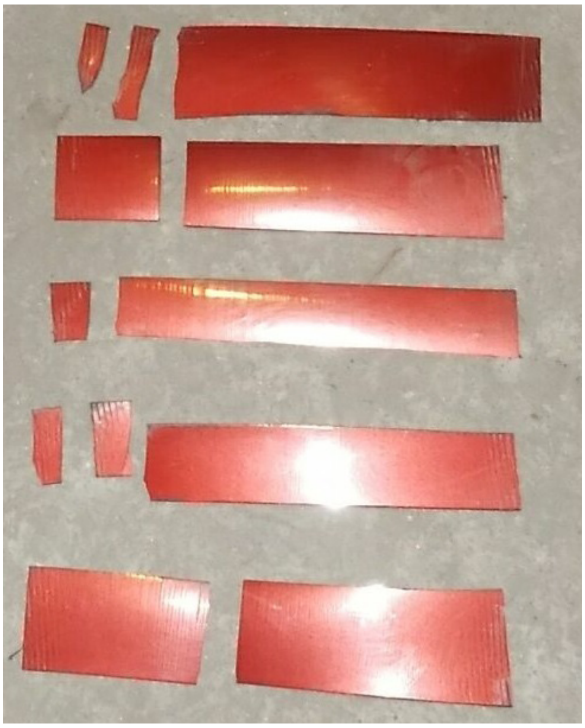

Fig. 3. Samples of polyamide elements (PPE-PA66)

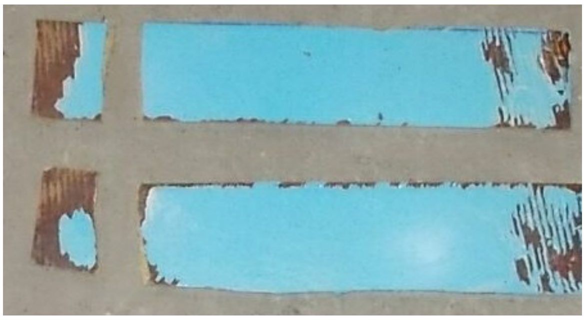

Fig. 4. Samples of elements from duroplast

In the case of lacquer coating, the lacquer was peeled off under the jaw of the machine.

Figure 5 shows samples of material from the Renault Espace III vehicle after the strength test. Due to the tendency of the material to slip from the jaw of the strength machine, Figure 5 shows the narrowing in the measuring part of the samples.

Figure 5 shows six samples cut from composite material after the tensile strength test. Samples 1, 2 and 3 come from a composite element (vehicle door), which was unaffected by impact during a collision. Samples 4, 5, and 6 are specimens cut from an element that has been subjected to a slight dents as a result of impact on the vehicle door during a collision.

Table 2 shows the results of the strength tests for the individual material samples.

By analyzing the data compiled in Table 2, the highest tensile strength was obtained for the material cut from the door of a vehicle involved in a road collision (maximum value 81 MPa), while for a non-collision element (maximum value 69 MPa). The lowest value was obtained for a body made from the front fender to a maximum value of 40 MPa. Intermediate values were obtained for components made of duroplast (maximum 47 MPa). Based on the combination, it can be seen that the tensile strength values of the tested ma-

Fig. 5. Samples of elements made of glass fiber reinforced composite

Table 2. Research results of composite materials samples

Sample	Width [mm]	Thickness [mm]	Cross-section [mm2]	Strength [kN]	Rm [MPa]
Clio no. 1	47	2.5	117.5	3.5	30
Clio no. 2	36.5	2.3	83.95	3.0	36
Clio no. 3	29	2.3	66.7	2.7	40
Clio no. 4	43	2.3	98.9	3.8	38
Clio no. 5	48	2.3	110.4	4.2	38
Clio aver.				**3.44**	**36.4**
Trabant no. 1	46	3.0	138	5,800	42
Trabant no. 2	45	3.0	135	6,400	47
Trabant aver.				**6,100**	**44.5**
Espace no. 1	12.1	2.7	32.67	2.25	69
Espace no. 2	14	2.6	36.4	1.57	51
Espace no. 3	17.1	2.9	49.59	1.66	56
E. aver. 1÷3				**1.83**	**58.66**
Espace no. 4	15.8	3.0	47.4	2.85	81
Espace no. 5	16	3.1	49.6	1.66	56
Espace no. 6	14.1	2.8	39.48	2.35	72
E. aver. 4÷6				**2.27**	**69.66**

terial samples show a fairly wide spread of values from 30 to 81 MPa. The fiberglass composite showed the greatest value of tensile strength and was one of the elements that were involved in the collision. The lowest values were obtained for the element made of Polyamide PPE-PA66.

CONCLUSIONS

Due to the stringent environmental requirements of the automotive industry, modern lightweight construction materials are increasingly being used in motor vehicles. Vehicles made of lightweight materials reduce the total mass of the vehicle, which translates into fuel economy and CO2 emissions reduction. In addition, for some materials (polymeric materials), there is lower production costs and shorter execution times for individual vehicle components.

The paper presents the results of structure and strength tests of composite car body elements that have been decommissioned but without damage to the bodywork as well as from plating parts which have been damaged during a traffic collision. As a result of the tests, it was found that the highest tensile strength was obtained for the samples of the material cut from the door of a vehicle involved in a traffic collision (average 69.66 MPa), while for a component not involved in the collision an average of 58.66 MPa. The lowest value was obtained for the bodywork of the front fender - average 36.4 MPa. Indirect values were obtained for components made of duroplast (44.5 MPa). It can be stated that the car body components of the safety cage exhibit higher tensile strength as passenger protection elements. In the case of body components that are in the front of the car body, the main impact forces are absorbed by the structural elements and vehicle stringers.

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