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MATERIALS AND TECHNOLOGIES IN MOTORIZATION IN THE ASPECT OF SAFETY AND ECOLOGY

The use of a particular material in the automotive industry is determined by its properties in the aspect of safety and the effects on the natural environment starting from production to its liquidation. We are constantly striving to reduce the costs of materials used while increasing the strength properties and the production of non-natural materials, e.g. composites. Among the modern materials appearing in the production of cars, a growing share of high-strength steels, plastics as well as light alloys based on aluminum and magnesium is observed. This article presents selected materials and technologies used in the automotive industry from the point of view of their impact on safety and environmental protection.

INTRODUCTION

The main requirements for currently produced automotive vehicles are increased safety of the structure while reducing vehicle weight, resistance to atmospheric conditions and meeting ecological standards. Research covering these issues is conducted all over the world. Due to the complexity and multitude of problems that accompany this subject, it has not been discussed at length yet [1-3]. A continuous development of the automotive industry is focused on the introduction of new construction materials that increase the passive safety of vehicles. New materials used in automotive industry could reduce the weight of vehicle by several percent. Simultaneously, the strength properties and the suitable technology must be maintained at the current level. The elements of vehicles and their engines made of materials that are lighter than the traditional ones, such as steel or cast iron, as well as new production technologies still constitute the possibility of their development [4-8]. Steel is widely used in the construction of vehicles. More and more new types of steel are developed. They are characterized by better strength properties and better energy consumption. The following steels are constantly used in the production of cars [9]:

- regular steels (e.g. for external plating);
- steels with increased durability (e.g. for load-bearing structures of modern cars, frame constructions - lorries);
- permanently resistant to corrosion (on truss, bus frames, skeletons of commercial vehicle bodies).

Some attempts have been made to use materials such as aluminum alloys, magnesium and titanium alloys as well as high-strength AHSS (Advanced High-Strength Steels) [10], including martensitic steel (Martensitic Stainless Steels) [11]. The role of AHSS steel will continue to grow, especially due to its mechanical properties. Composite materials are also becoming more and more applicable, making it possible to obtain hitherto unachievable properties of parts subjected to extreme loads (e.g. brake disks, pistons, etc.). The possibility of a significant improvement of mechanical properties of materials by the so-called reinforcement (composite), e.g. with metallic or ceramic fibers, causes such materials to be the materials of the future in the automotive industry, especially in the construction of lightweight car bodies. The combination of different materials forming a single vehicle structure is predicted to be a solution of this problem in the automotive industry [12].

Strict standards to protect the environment affect not only the construction of engines and transmission systems in the sense of better economics of combustion processes and minimization of rolling resistance, but also for the improvement of self-supporting bodies in terms of weight reduction and aerodynamic improvement.

1. STEEL IN AUTOMOTIVE INDUSTRY

Materials used in the production of cars, especially car bodies and vehicle covers should be characterized by high surface quality, easy processing and they should have high energy consumption. The current technology for the production of car bodies has been mainly based on using mild steel. According to the current state of knowledge, they can be classified into three basic groups (Fig. 1) [13]:

- soft, plastic low-carbon steels (DQSK, IF steels) with short-term tensile strength R_m below 300 MPa and total elongation A in the range of 30 ÷ 60%;
- HSS high strength steels (BH, CMn, IF with micro additives, HSLA) of 300 <R_m <700 MPa and reduced A in relation to the previous group;
- steels with very high AHSS strength (R_m over 700 MPa, reaching even 2000 MPa) and elongation contained within quite wide limits 5 ÷ 30%, while the strength increase leads to a decrease in plasticity.

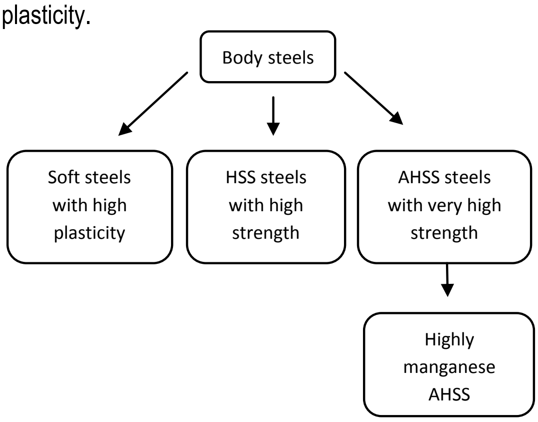

Fig. 1. *Steels in the automotive industry*

BH and HSLA steels are used in the elements responsible for safety. Obtaining such large admissible values of R_m is possible by applying a heat treatment. BH steel is a steel that is strengthened under the influence of temperature, e.g. when heating the lacquer layer to dry and harden. As a result of the rolling, the grains of the material become flattened. As a result of heating, a new, more durable structure is created. Then the whole thing slowly cools down. On the other hand, achieving high mechanical properties in the case of HSLA (High Strength Low Alloy) steel is possible due to additives in the form of admixtures of other elements, such as titanium or niobium. These plates absorb energy well, which is why they are used in elements responsible for safety, such as thresholds, floors, posts and other parts that create zones of controlled crumple [14].

Due to the need to reduce the weight of the vehicle, materials with high strength and good plasticity are used. A new generation of multiphase steels of high and very high strength - AHSS (Advanced High Strength Steel) acquires a dominant role, especially for load-bearing structures. They are characterized not only by very high strength, but also high plasticity. It is a very technologically advanced material. Its yield strength Re exceeds 1000 MPa. The use of AHSS steel reduces the mass of the vehicle structure because it is durable enough to use thinner sheets. The great advantage of this material is also the relatively low price. It results from a small number of applied alloy additives. Another good advantage of AHSS steels are also good technological properties, such as weldability or compression. Elements made of such sheet are used in key elements of the vehicle, affecting the safety of travelers [14]. Figure 2 shows the share of individual steel groups in the total weight of the average car body in the USA in 2005 and 2015. It can be clearly seen that the share in soft steels decreases in favor of high-strength steels.

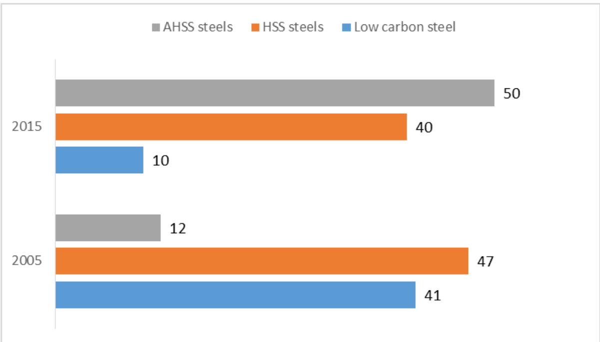

Fig. 2. *Share of particular steel groups (in %) in the total weight of the average car body in the USA in 2005 and 2015, based on [13]*

Another group of very durable steels are high-manganese TWIP and TRIP steels. TWIP steel appeared in the market in 2004. It is characterized by an exceptionally high degree of deformation while maintaining high strength. This is a unique property, especially important in the event of a vehicle collision. Under these conditions, the material should exhibit two opposite features:

- high ductility to absorb the maximum amount of impact energy when plastic deformation;
- maintain the maximum stability of the element that protects the passenger cabin.

The steels used until now were either very durable (from which, for example, a car frame was made), but not very ductile, cracking under excessive dynamic load, or vice versa: plastic, but not durable. TWIP steels can revolutionize this segment. A number of such unique materials have been received so far, including in Germany [8], Korea [9] and Japan [10]. The chemical composition of TWIP steel is characterized by a high content of manganese (15 ÷ 35%), other alloy additives are 2 ÷ 4% Al and / or Si. The high Mn content stabilizes the austenite to room temperature [13].

Steel construction materials with increased, high and ultra-high strength allow to reduce the overall weight of the body skeleton. At the same time, however, they increase the cost of its implementation and the costs of subsequent repairs because they are much more expensive than standard ones and require more expensive processing. Therefore, a technology, that enables optimal differentiation of strength not only in relation to individual structural parts of the structure, but also to their integral fragments, has been created.

Metallurgical, semi-finished products known as tailored blanks have such properties. These are multifunctional packages consisting of laser-welded different types of sheet metal, e.g. deep-drawn, high-strength and high-strength. Each of these components has a different function in the package. The deep-drawn sheet absorbs the impact energy during a possible road collision. The material with increased strength deforms when the deep-well sheet failed to dissipate the entire collision energy. The stiffest element can, at the same time, undergo only slight deformation, because its task is to preserve the rigidity of the vehicle's cabin, i.e. survival space for the driver and passengers [1].

In modern bodies, tailored blanks are used to locally stiffen heavily loaded construction nodes or to reduce the overall weight of the vehicle by using less thick sheet metal in less loaded parts, e.g. in some parts of the floor panel. The method of joining non-identical steel materials is now commonly used also in relation to structural closed profiles with variable cross-sections, as well as during the creation of so-called. deformation zones. These products are called "tailored tubes".

The production of tailored blanks and tailored tubes is handled by specialized metallurgical plants with technological lines suitable for steel processing methods with the highest strength and minimal plasticity. In standard production departments of body moldings, such equipment would be unprofitable even in the largest vehicle factories.

The highly specialized methods of making drawpieces include:

- hot stamping, i.e. hot stamping of sheet metal parts that cannot be cold formed;
- hydroforming, where precise die stamping takes place under hydrostatic pressure of very high pressure liquids;
- tailored tempering consisting in thermal treatment of selected zones of a uniform sheet metal stamping (e.g. B-pillar) in order to impart diversified strength properties to its individual parts.

The biggest advantage of hydroforming is the shaping of products during one operation, unfortunately at the expense of the operation time, which can significantly increase depending on the material. Finished products are also characterized by high dimensional accuracy [15].

Prefabricated elements cannot be repaired in the course of road collisions after being damaged, but only exchanged for new and original ones, using binding techniques established by the vehicle manufacturer.

2. ALUMINIUM AND MAGNESIUM ALLOYS

In modern cars and trucks, aluminum displaces constantly. This is due to saving in energy consumption and reducing vehicle weight. This translates directly to a reduction in average fuel consumption, and thus the emission of pollutants of exhaust gases, while maintaining high safety requirements. Aluminum is used primarily as an alloy with other metals. It is usually mixed with elements such as Si, Cu and with additions of Mg and Mn for better plastic forming. For various reasons, aluminum alloys are more expensive to manufacture than steel, but if you consider their advantages and disadvantages, they are more advantageous to use. In the vehicle, the total weight of parts made of light alloys based on aluminum is currently approx. 130 kg. Aluminum alloys are also more and more often used for car, bus or utility truck coverings. The use of aluminum in the construction of the body can be divided into three categories. The first one can include cars, whose shells of individual car body elements were made of light alloys (e.g. Ford F150). Their construction was based on steel supporting frames. In the second there are so-called hybrid bodies, i.e. connecting aluminum and steel elements, e.g. BMW 5 Series (F10). Metal lighter reduces their overall weight, and steel optimizes mechanical strength and facilitates the connection of individual elements to larger structures using classical welding techniques (Fig. 3).

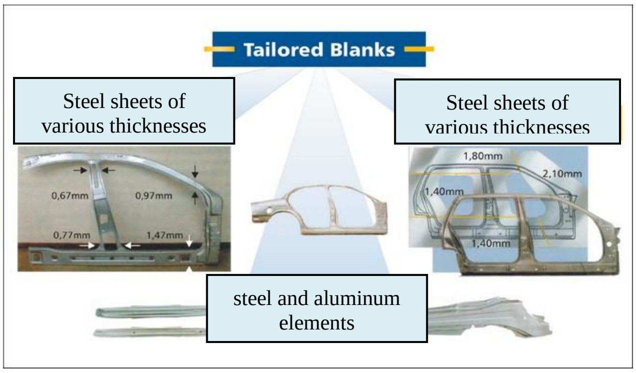

***Fig. 3.** Multilayer elements obtained thanks to the use of new technology, based on [15]*

The third category includes constructions made largely of light alloys, e.g. Audi A8 (D4). Its supporting structure was made almost entirely of aluminum. The only exceptions are middle posts made of high-strength steel. For example, Jaguar XE uses aluminum in the construction to a lesser extent, for about 75%. Aluminum is widely used in the automotive industry, including buses and lorries [16]. Figure 4 shows areas of application of aluminum in the construction of a car. Bodywork Audi TT made almost entirely of Al sheet.

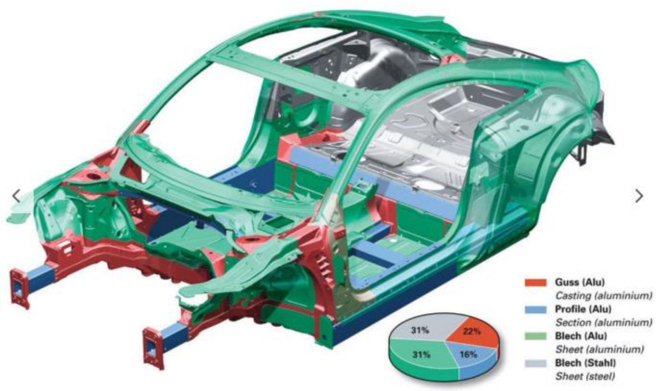

***Fig. 4.** Areas of application of aluminum in the construction of a car. Bodywork Audi TT made almost entirely of Al sheet (except the rear part of the body with reinforcements) [16]*

On the other hand, each aluminum material has a significant (compared to most iron alloys) corrosion resistance, and once produced it is suitable for repeated recycling, and much cheaper than in the case of steel scrap. In the load-bearing structures of vehicles, an additional and very important advantage of aluminum alloys, especially used in the form of closed thin-walled profiles, is their high plasticity, thanks to which small and medium post-accidental deformations do not transfer to further parts of the body structure.

Magnesium alloys are also used in vehicles. Their characteristic feature is very low weight (magnesium – 1.74 g/ cm^3), but they are characterized by reduced strength, are prone to breakage and sensitive to corrosion. Interest in magnesium alloys is growing due to the possibility of using thin-walled castings (wall thickness of approx. 1.5-3 mm). These alloys are used for skeletons of vehicle equipment components (e.g. seat skeletons, steering wheels, etc.). Increasingly described feet are used in braking systems or on wheel rims. They are also used under the hood of the vehicle, for example, the connecting rods of sports car engines or gearbox housing (Fig. 5).

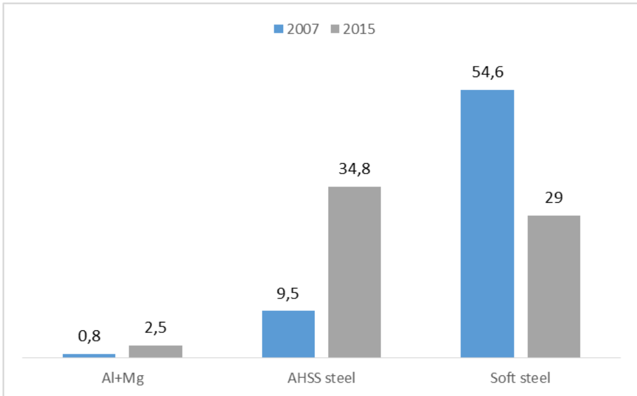

***Fig. 5.** Percentage of selected materials in the car body structure [1]*

The use of light metal plating favors weight reduction and provides higher corrosion resistance. Corrosion is particularly exposed to city buses, garages in the open space and operated in difficult conditions, exposed to exhaust gases or chemical agents for cleaning street surfaces in cold winter conditions.

3. PLASTICS

Plastics (polymeric materials) belong to the group of amorphous materials. They are characterized by relatively good mechanical properties, they are electro-insulators and are resistant to chemical agents. The advantages of plastics include low specific gravity. The disadvantage is the low resistance to high temperatures (above 200-300°C) [9]. Currently, plastic is used in vehicles more and more often. Today's mass-produced cars and trucks contain about 200-300 elements made of plastics with a total weight of 40-100 kg per vehicle. Plastics are used in cars to make interior fittings, engine covers, boot covers, bumpers, fenders, side and threshold strips, wheel arches, thermal and acoustic engine covers, instrument panels, roof liners, door linings, sides and floors, fluid tanks, lines (e.g. fuel, brake) etc.

Currently, polymer materials are used in more than 1000 car components. So-called macromolecular materials account for 10-15% of the mass of a mid-class passenger car. The most polymers (about 60%) are used to finish the interior, in the body there are about 30%. The rest is intended for the shields of the drive unit and chassis finishes. It covers elements from several dozen grams to several kilograms. In the average car there is about 2 thousand elements made of polymeric materials. The dominant position among polymers used in vehicles is polypropylene, which results from the widespread use of this polymer for the production of bumpers, which reduces vehicle weight and fuel consumption [17].

4. COMPOSITES

Composite materials are created so that the obtained material has better properties than the components used separately. The composite is a monolithic material, but with visible boundaries between the components. One of the first cars to use composites to a large extent was the Porsche Carerra GT (production 2004-2006). CFRP composites with an epoxy resin matrix were used for the construction of its chassis. Another example is Bugatti Veyron. It is largely made of carbon fibers. Composites are also used in Audi, for example the A8 W12 can be retrofitted with ceramic brake discs made of silicon carbide (chemical designation: SiC) reinforced with carbon fibers. This allows to reduce the weight to 5 kg while improving the braking system's performance (more effective braking, less susceptibility of the discs to heating up, less susceptibility to wear).

The use of composite materials in the automotive industry is forward-looking and will be disseminated to an increasing extent. Currently, they are used to reduce the weight of vehicles, and in some cases also to strengthen the structure. For instance, car wheel liners adapted to drift are made of composites, these materials are also used in Formula 1 cars. The car bodies and load-bearing structures are also largely made of carbon fiber. This improves the quality of the structure, reduces the weight of the vehicle, reduces fuel consumption and, importantly, reduces the emission of harmful substances (currently this is a priority when building modern cars).

CONCLUSIONS

In the automotive industry, various metal and non-metallic materials are used for the production of motor vehicles. The use of a particular material is determined by its properties in terms of safety and environmental effects, from production to its liquidation. Hence, more and more funds are spent on research and development of construction materials. We are constantly striving to reduce the costs of materials used while increasing the strength properties and the production of non-natural materials, e.g. composites. Among the modern materials appearing in the production of cars, a growing share of high-strength steels, plastics - polymers as well as light alloys based on aluminum and magnesium is observed. The increasing demands placed on the automotive industry in the field of ecology mobilize scientists, engineers and manufacturers to work on the design of such materials that will ensure not only better traction of vehicles or greater driving comfort, but will reduce their negative impact on the environment. We also strive to develop new technologies that enable optimal diversification of strength not only for individual structural parts but also for their integral fragments.

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Materiały i technologie w motoryzacji w aspekcie bezpieczeństwa i ekologii

O zastosowaniu konkretnego materiału w motoryzacji decydują jego właściwości w aspekcie bezpieczeństwa i skutków dla środowiska naturalnego począwszy od produkcji do jego likwidacji. Ciągle dąży się m.in. do obniżenia kosztów stosowanych materiałów przy jednoczesnym zwiększeniu właściwości wytrzymałościowych oraz wytwarzaniu materiałów niewystępujących w przyrodzie, np. kompozytów. Wśród nowoczesnych materiałów pojawiających się w produkcji samochodów obserwuje się rosnący udział wysokowytrzymałych stali, tworzyw sztucznych, a także stopów lekkich na bazie aluminium i magnezu. W artykule przedstawiono wybrane materiały oraz technologie stosowane w przemyśle motoryzacyjnym z punktu widzenia ich wpływu na bezpieczeństwo i ochronę środowiska.

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JEL: Q01**DOI**: 10.24136/atest.2018.060

Data zgłoszenia: 2018.05.21 **Data akceptacji**: 2018.06.15