Alexander BALITSKII
Karpenko Physico-Mechanical Institute, Ukrainian National Academy of Science, Lviv, Ukraine, West Pomeranian University of Technology, Faculty of Mechanical Engineering and Mechatronics
balitski@ipm.lviv.ua
Małgorzata MROZIK, Karol Franciszek ABRAMEK
West Pomeranian University of Technology, Faculty of Mechanical Engineering and Mechatronics
mmrozik@zut.edu.pl, kabranek@zut.edu.pl
Jarosław CHMIEL
Maritime University in Szczecin, Institute of Transport Engineering
j.chmiel@am.szczecin.pl

MATERIAL CHANGES IN THE CONSTRUCTION OF PASSENGER AND CARGO VEHICLES

Key words

Automobile, eco-design, construction vehicles, materials.

Abstract

Automobiles are very important elements of economic and social life. Its development is accompanied by its increasing use as a means of transport. This produced a significant increase in the number of vehicles, which are realized through the increasing global consumption of raw materials from year to year. Great progress in the automotive industry in the construction of the body, chassis, and engines are mainly introduced through the use of new materials to build vehicles, and they have a direct impact on their weight, performance, and fuel consumption. The article presents some aspects regarding material changes in the construction of passenger vehicles. In a simplified manner, the analysis of

changes in the use of construction materials for the construction of selected vehicles is presented.

Introduction

The global automotive industry is currently undergoing changes related to the ongoing global problems of environmental degradation. This forces automotive manufacturers to continuously improve their design in order to meet the new demands of customers. Progress in the field of automotive design enforces certain changes in the structure of materials and manufacturing technologies that are increasingly being optimized in terms of their impact on the environment. Reducing the harmful effects of the production of motor vehicles is mainly associated with the use of technological processes with the lowest energy consumption and toxicity and plant protection against the emission of harmful pollutants into the environment.

Great progress in the automotive industry in the construction of body, chassis, and engines is primarily accomplished through the introduction of new materials, and they have a direct impact on their durability, weight, safety, and fuel consumption [1]. Material science advances in the area of vehicle technology have resulted in easier processing of light, high strength and corrosion-resistant materials, such as modern aluminium alloys and modern plastics, which have significantly displaced traditional high-grade steels or forgings and castings, and cast iron [2–5]. The main materials that are used in the construction of passenger vehicles should include the following [6–9]:

- Carbon steels and high alloy materials from cast iron and steel (e.g. forgings, castings);
- Light metals (aluminium alloys, magnesium alloys, titanium alloys);
- Other non-ferrous metals (e.g. Zinc, copper, etc.);
- Polymers (polyurethane, polypropylene, polyethylene, polycarbonate, etc.) and rubber;
- Other materials (including composites); and,
- Consumables and auxiliary materials (e.g. brake fluid, refrigerant, oil, etc.).

1. Requirements for materials used in the automotive industry

The current requirements for construction materials used in the automotive industry trend are primarily the use of materials of lower density and higher strength, and superior performance (Fig. 1). This makes it possible to reduce vehicle mass and thus reduce fuel consumption, which is associated with the lower vehicle emissions of carbon dioxide into the environment. The use of new construction materials and supplies as well as manufacturing technology should contribute to an increase in the life cycle of vehicles and their components. This reduces the environmental load of waste materials associated with servicing and the liquidation of used vehicles. It also saves raw materials and the energy required to process the materials and manufacturing vehicle parts and assemblies. New materials and the design of the vehicle itself should be adapted to the efficient recycling of vehicles. An important feature of the new materials should be their biodegradation. Analogous requirements are also transport infrastructure, especially consumables due to the emission of substances harmful to the environment.. This also applies to the fuel, which the reduction of harmful substances, eg. sulfur and aromatic hydrocarbons is required (these impurities, reduce the exhaust after treatment devices effectiveness). In contrast, for economic reasons, it is desirable that the cost of materials and technology components of vehicles and the transport infrastructure and supplies are kept relatively low. This task is difficult to meet. Many ecological solutions in the automotive industry are associated with reducing costs prove less favourable for the environment [6, 7, 10, 11].

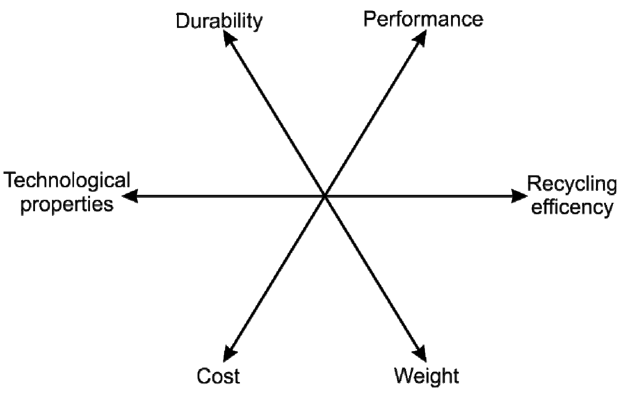

Fig. 1. Basic criteria of material selection in automotive industry

2. The model of a passenger vehicle

The motor vehicle is a very complex system, which is characterized by significant variation in design and materials. In the construction of a motor vehicle, one can distinguish several basic systems associated with the drive, braking and steering. Widely accepted divisions of the vehicle systems and assemblies can be found in the papers [12–16]. The basic assumption of the model is shown in Fig. 2, which includes the analytical modelling of a passenger vehicle’s production phase, including the first stage of its division into units (Z), which is divided in the following order of the components in the (P) consisting of various materials (m).

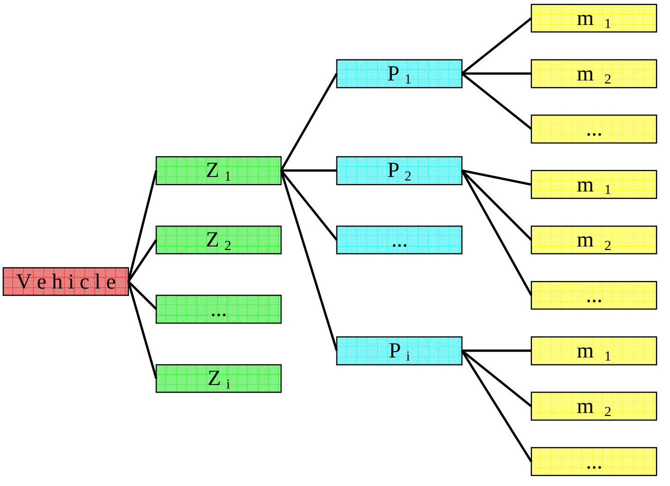

Fig. 2. Structure of decomposition model passenger vehicle

3. Assessment of changes in materials in the construction of a passenger vehicle

The percentages of the mass of individual materials in the construction of a passenger vehicle are based on data collected in selected SDP for six variants of one of the most popular car models in Europe and in the world – VW Golf. The basis for the analysis of changes in materials in the construction of the passenger vehicle was to determine the initial structure of the material, including the individual masses of the materials that make up the vehicle immediately after its production in the assembly manufacturer with a special analysis of the elements made of plastics. The same is true of non-ferrous metals (copper, zinc, tin, nickel, magnesium). Percentages of non-ferrous metals by weight relative to the weight of the whole vehicle in successive versions of the VW Golf increased from just over 1% in 1974 (version A1) to more than 2% in 2009 (v.A6).

For the construction vehicles are used in a variety of materials. Their composition and participation in the mass of the vehicle have a significant impact on the course and the effectiveness of recycling. The determination of the material composition of vehicles is difficult because each manufacturer's vehicles have a different structure. However, the average share of car weight materials is as follows:

- 70% – Metals;
- 17% – Liquids, glass, rubber, textiles and other materials;
- 13% – Plastics.

Changes in the composition of the material in the construction of automobiles are primarily due the environmental and safety requirements of the buyers having regard to their comfort, quality, durability, fuel consumption, and also with the principles of competitiveness. With the development of automotive and technical progress, the changing weight of each part of the vehicle as is apparent from Figs. 3–6. The impact of individual variants of passenger car model VW Golf on the structure of the material in the construction phase is visible mainly in the use of aluminium alloys and plastics, which confirms the trend of increased participation of these materials in vehicle technology. However, with each new version of the car, the weight of steel relative to the total weight of the vehicle decreased. Therefore, there is a significant reduction in the materials such as steel, cast steel and cast iron (a reduction of approx. 10%) for materials such as aluminium and its alloys (an increase of more than 2% of the weight of the entire vehicle), or plastics and rubber (an increase of almost 5% of the weight of the entire vehicle).

Basic steels, cast steel, cast iron

The percentage by mass of each material with respect to the weight of the whole vehicle (VW Golf) is shown in Figs. 3–6.

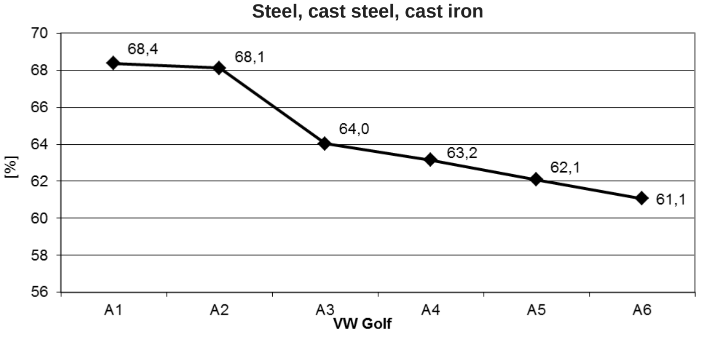

Fig. 3. Percentage of the weight of steel, cast steel, and cast iron in relation the weight of the whole vehicle (VW Golf) 1974-2009

In the VW Golf, elements of steel, cast steel, and cast iron in the mid-70s (version A1) accounted for almost 70% of the entire vehicle. With each new version of the car, the weight of steel elements relative to the total weight of the vehicle decreased. In the case of the A6 version of the 2009, the percentage weight of steel fell almost 10% in comparison with the A1 version 1974 (slightly more than 60%).

Aluminium alloys

The share of aluminium and its alloys with each new version of the VW Golf increased. In the early years of production (version A1), aluminium, and its alloys were less than 6% by weight of the whole vehicle. In the version of the A6 VW Golf with 2009, the percentage weight of aluminium components amounted to more than 8% of the weight of the vehicle.

Other non-ferrous alloys

The same is true of non-ferrous metals (copper, zinc, tin, nickel, magnesium). The percentage of non-ferrous metals by weight relative to the weight of the whole vehicle in successive versions of the VW Golf increased from just over 1% in 1974 (version A1) year to more than 2% in 2009 (version A6).

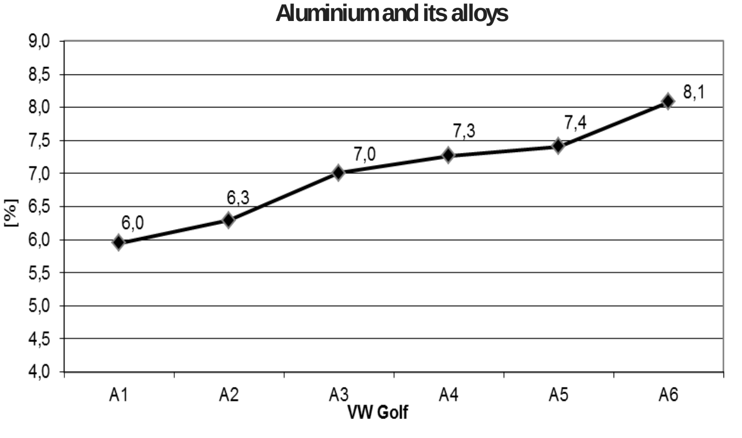

Fig. 4. The percentage by weight of aluminium and its alloys compared to the weight of the whole vehicle (VW Golf) 1974–2009

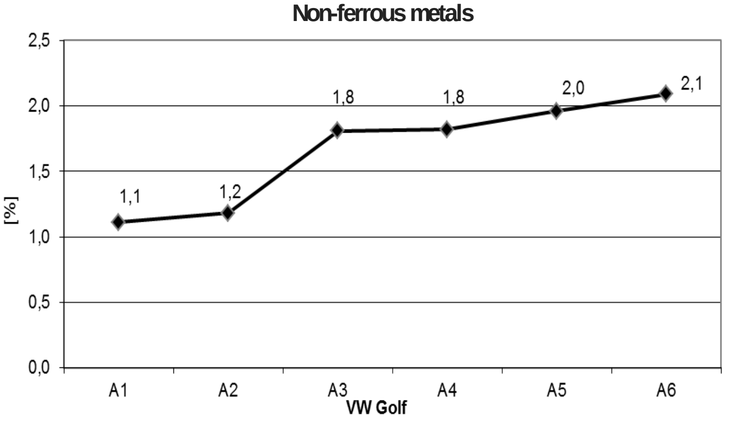

Fig. 5. Percentage of non-ferrous metal mass in relation to the weight of the whole vehicle (VW Golf) 1974-2009

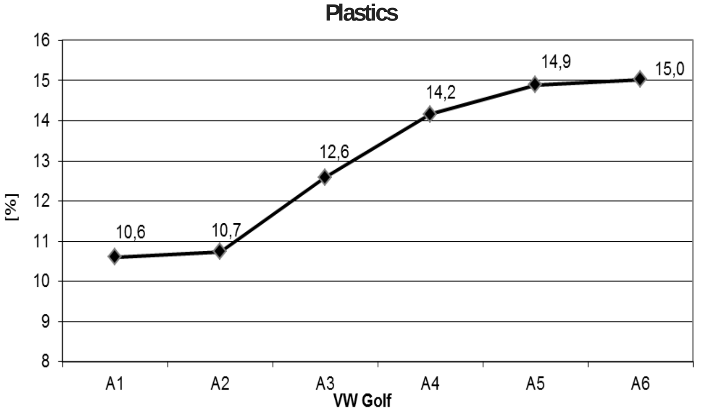

Fig. 6. Percentage of the weight ratio of plastic to the weight of the whole vehicle (VW Golf) 1974–2009

Steels with high strength and wear resistance

There are two essential premises for the application of high tensile (HT) steels in the construction of motor vehicles:

– The reduced of unloaded vehicle mass, and
– The increased strength and rigidity of the structure.

The first aspect is particularly important in the construction of trucks. The use of HT steel in the elements of the supporting frame allows minimizing weight of the truck. For trailers this can be as low as about 4000 kg. The weight loss resulting from the use of HST steels is estimated to be approximately 800 kg. Currently, weldable HST steels constitute up to 50% of the materials used in the construction of trailers. The role of these steels will gradually increase, with increasing participation of large trucks in road transport [18, 19].

The second aspect (increased strength and rigidity of the structure) is particularly important in the construction of passenger vehicles. Rigidity and resistance to stress of the roll cage in road traffic collisions are critical to minimize injuries to passengers. Steels of this type have been used for that purpose for over 20 years, and their weight proportion in the construction of passenger vehicles has increased from 5% to 20%. Particularly attractive are the advanced ferritic-bainitic or ferritic-martensitic steels (known collectively as advanced high-strength steels, AHSS), subject to thermo-plastic processing [20, 21].

An extreme case of high-strength materials are maraging steels. US Patent 6475307 from 2000 describes a technology for the production of automotive components from those steels. Their high price, however, limits their use to those cases where the service life is most crucial [22], for example diesel injection systems [23]. Apart from the high strength and stiffness, long service life is one of the most desirable features of structural materials. This issue is particularly important in the construction of vehicles for the transport of bulk cargo, such as aggregates, fossil fuels, and waste. The combined effects of erosion and corrosion may dramatically shorten the service life of conventional steels. In physico-chemically active environments, typical corrosion processes may also be accompanied by hydrogen degradation processes of materials, leading to susceptibility to brittle fracture (Fig. 7) [24] and reduced resistance to erosion fatigue (Figure 8) and erosion (Figure 9) [25].

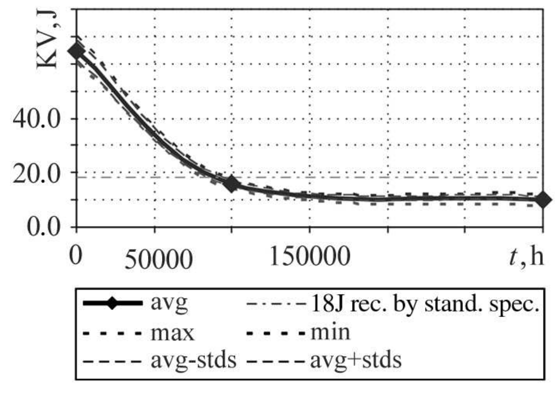

Fig. 7. A decrease in toughness according to Charpy 18Mn2 under long-term operation in environments rich in hydrogen [24]

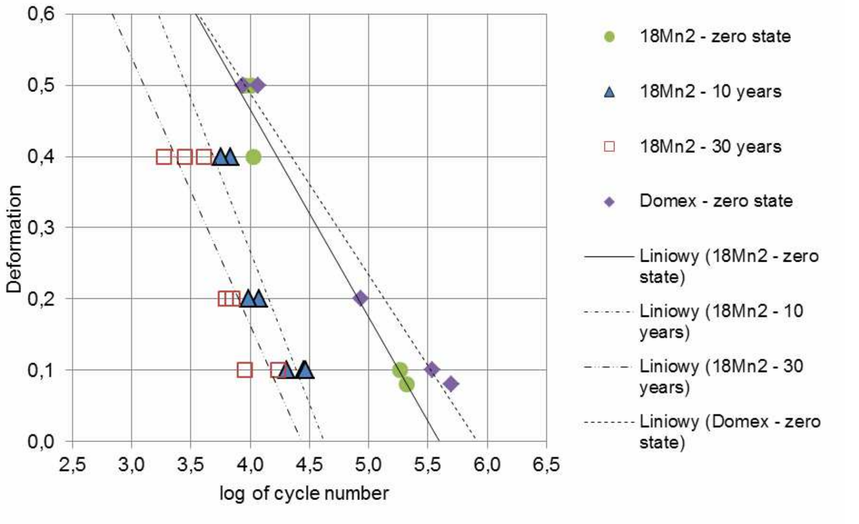

Fig. 8. The results of low-cycle fatigue tests of 18Mn2 steel and micro-alloyed Domex steel [25]

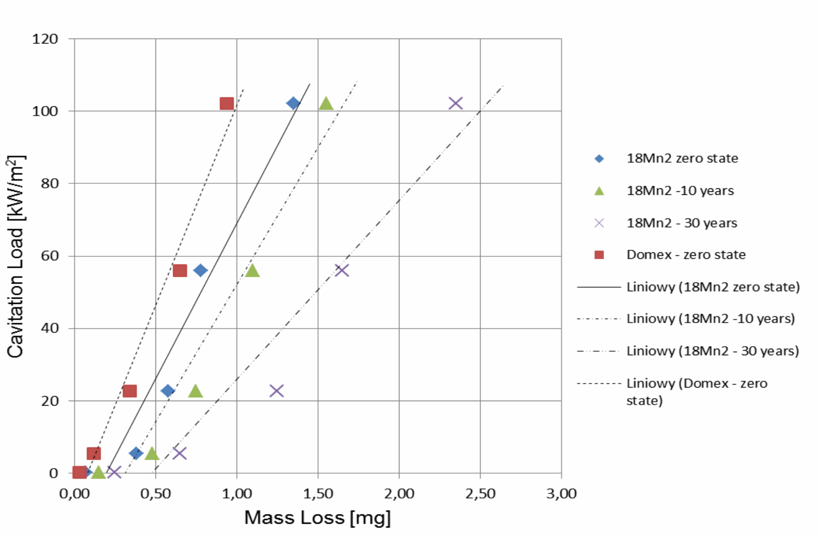

Fig. 9. The loss of mass of 18Mn2 and micro-alloyed Domex steels in cavitation with variable load; time [25]

The higher resistance of micro-alloyed boron steels to erosion and corrosion makes it possible to use them in extremely difficult conditions of bulk cargo, usually associated with severe abrasion and corrosion [26–28]. In addition, the high resistance of these steels to fatigue justifies their increasingly common use as a structural material of in monocoques and chassis. A similar range of applications is indicated for the advanced high-strength steels [29–32].

Magnesium alloys

The growing role of magnesium alloys in automotive engineering is mainly due to their low density. The use of Mg alloys can reduce vehicle weight by more than 100kg. This translates into a reduction of CO2 emissions by more than 5% [33].

Property	Magnesium	Aluminium
Density at 20°C (g/cm^3)	1.74	2.70
Elastic modulus (10^6 MPa)	44.126	68.947
Tensile strength (MPa)	~240	~320

The main advantages of magnesium alloys include the following:

- The preferred ratio of elastic modulus to density,
- Good casting properties, and
- Good damping capability.

Their main disadvantages are relatively low corrosion resistance (which requires the unconditional application of anti-corrosion protection), a susceptibility to hydrogen cracking, and the risk of ignition. The first attempts to use Mg alloys were made after 1920 (Porsche 1928, Bugatti 1935), mainly in motorsports [34].

A comprehensive overview of the use of magnesium alloys in automotive engineering was conducted by Kulekci [35]. The applications of Mg and its alloys include the chassis, car body components, and the drive unit. It is indicated that even more than 20 kg of Mg and its alloys may be used in mass car production. The manufacturing of Mg alloys is based mainly on different varieties of casting processes with particular emphasis on high-pressure die-casting. The processes of squeeze-casting [36, 37] are also technologically promising.

Summary

Automobiles are very important elements of economic and social life, and their role is transportation is increasing. The article presents some aspects regarding material changes in the construction of a passenger vehicle in a simplified manner.

References

1. Balitskii A.I., Abramek K.F., Stoeck T., Osipowicz T.: Diagnostics of degradation of the lock of a sealing ring according to the loss of working gases of an internal combustion engine. Materials Science. Vol. 50, No 1, (2014), pp. 156–159. ISSN 1068-820X.
2. Chłopek Z.: Pojazdy samochodowe. Ochrona środowiska naturalnego. Wydawnictwa Komunikacji i Łączności, Warszawa (2002).
3. Merkisz J.: Ekologiczne problemy silników spalinowych. Wydawnictwo Politechniki Poznańskiej, Poznań (1998).
4. Merkisz J.: Ekologiczne aspekty stosowania silników spalinowych. Wydawnictwo Politechniki Poznańskiej, Poznań (1995).
5. Merkisz J.: w „Technologie zero emisji”.
6. Dobrosz K., Matysiak A.: Tworzywa sztuczne w pojazdach samochodowych. Wydawnictwa Komunikacji i Łączności, Warszawa (1982).
7. Jeznacki J.: Materiałoznawstwo samochodowe. Wydawnictwa Komunikacji i Łączności, Warszawa (1973).
8. Balitskii A.I., Mrozik M., Abramek K.F., Eliasz J.: Analysis of selected material and energy aspects related to the construction chase of a delivery vehicle life time. Fracture Mechanics of Materials and Structural Integrity.

Proceedings of the 5thInternational Conference. Lviv, Ukraina (2014), pp. 841–847. ISBN 978966-02-7249-1.
9. Majak M.: Tworzywa sztuczne w samochodach. Auto-Technika Motoryzacyjna 2 (1999).
10. Idzior M.: Kierunki zmian materiałowych w motoryzacji w świetle wymogów ekologii. Motrol 9 (2007).
11. Mrozik M.: Wybrane aspekty zmian materiałowych w budowie pojazdu osobowego. Autobusy: Technika, Eksploatacja, Systemy transportowe. Nr 10 (2013), s. 193–195, 4 rys. ISSN 1509-5878.
12. Bernhardt M.: Podwozie samochodu budowa i obsługa. Wydawnictwa Komunikacyjne, Warszawa (1954).
13. Fudalej E., Fudowicz P., Humienny Z., Kosacki T., Ocioszyński J., Skawiński P.: Budowa pojazdów samochodowych. Cz. 1 i 2. Wydawnictwo REA, Warszawa (2010).
14. Fundowicz P., Radzimierski M., Wieczorek M.: Konstrukcja pojazdów samochodowych. Wydawnictwo Szkolne i Pedagogiczne, Warszawa (2010).
15. Gabrylewicz M.: Podwozia i nadwozia pojazdów samochodowych 1. Podstawy teorii ruchu i eksploatacji oraz układ przeniesienia napędu. Technik pojazdów samochodowych. Wydawnictwa Komunikacji i Łączności, Warszawa (2009).
16. Orzełowski S.: Budowa podwozi i nadwozi samochodowych. Wydawnictwa Szkolne i Pedagogiczne, Warszawa (1969).
17. Information on http://www.volkswagen.pl/recykling/.
18. Jian Bian et al.: Application potential of high performance steels for weight reduction and efficiency increase in commercial vehicles, Adv. Manuf. (2015) 3:27–36,
19. Haensch W., Klinkenberg C.: Low carbon niobium alloyed high strength steel for automotive hot strip. Ironmaking & Steelmaking (2005) 32(4):342–346.
20. ULSAB-AVC Body Structure Materials, Technical Transfer Dispatch No. 6, May, 2001.
21. Kuziak P., Kawalla R., Waengler S.: Advanced high strength steels for automotive industry, Archives Of Civil And Mechanical Engineering, vol. VIII, (2008), No.2. pp. 103–117.
22. Method for fabricating vehicle components and new use of a precipitation hardenable martensitic stainless steel. Patent US6475307 B1.
23. Materials for fuel injector components, Patent US 20100025500 A1.
24. Balitskii A.I., Chmiel J., Trojanowski J.: Degradation of steels in the hulls of river ships, Material Sciences, vol. 42, (2007) No.3, pp. 434–438.

25. Balitskii A.I., Chmiel J.: Resistance of Plates Shipbuilding Steels to Cavitation-Erosion and Fatigue Fracture, Material Sciences, vol. 50, (2015), No. 5, , pp. 736–739.
26. Kuzin O.A.: Control over the Properties of Microalloyed Steels by the Parameters of Internal Interfaces, Materials Science, vol. 36, (2000), No. 5, pp. 755–760.
27. Jha A.K. et al.: Correlating microstructural features and mechanical properties with abrasion resistance of a high strength low alloy steel, Wear, vol. 254, iss. 1–2, (2003), pp. 120–128.
28. Ojala N. et al.: Effects of composition and microstructure on the abrasive wear performance of quenched wear resistant steels, Wear, vol. 317 (2014) pp. 225–232.
29. Tamarelli C.M.: AHSS101: The Evolving Use of Advanced High-Strength Steels for Automotive Applications, www.steel.org/~/media/Files/Autosteel/Research/AHSS/AHSS 101.
30. http://automotive.arcelormittal.com/europe/products/AHSS/DP/EN.
31. Takahashi M.: Development of High Strength Steels for Automobiles, Nippon Steel Technical Report No. 88 July (2003).
32. Cornette el al.: High Strength Steels for Automotive Safety Parts, SAE Technical Paper 2001-01-0078, 2001, doi:10.4271/2001-01-0078.
33. Dietzel W. et al.: Hydrogen Embrittlement and Wear of Magnesium Alloys, Conference Wear Processes (2009), Szczecin.
34. Moity C. (editor) Les 24 Heures du Mans 1949–1973, Edita Lausanne (1974).
35. Kulekci M.K.: Magnesium and its alloys applications in automotive industry, Int. J. Adv. Manuf Technol (2008) 39:851–865, DOI 10.1007/s00170-007-1279-2.
36. Hu H.: Squeeze casting of magnesium alloys and their composites, Journal of Materials Science, March (1998), Volume 33, Issue 6, pp 1579–1589.
37. Brooks R.: GM Producing Squeeze-Cast Magnesium Auto Parts, http://foundrymag.com/ meltpour/gm-producing-squeeze-cast-magnesium-auto-parts; access: 10. 12.2015.

Acknowledgements

This research outcome has been achieved under the research project No 5/S/IIT/2014 "Environmentally assisted brittle cracking in the wear processes of infrastructure and transportation media", financed from a subsidy of the Ministry of Science and Higher Education for statutory activities.

Zmiany materiałowe w budowie pojazdów osobowych i towarowych

Słowa kluczowe

Pojazdy samochodowe, projektowanie ekologiczne, konstrukcja pojazdów, materiały.

Streszczenie

Motoryzacja jest jednym z najważniejszych elementów życia gospodarczego i społecznego. Jej rozwojowi towarzyszy przede wszystkim zwiększenie liczby wykorzystywanych środków transportu, w szczególności pojazdów mechanicznych. Wzrost liczby użytkowanych i wytwarzanych pojazdów przekłada się na zwiększenie globalnego zużycia. Jednym z istotnych czynników rozwoju motoryzacji w konstrukcji nadwozia, podwozia lub silników są przede wszystkim nowe materiały do budowy pojazdów, które mają bezpośredni wpływ na zmniejszenie ich masy, zmniejszenie zużycia paliw i ogólne zmniejszenie oddziaływania środowiskowego. W artykule przedstawiono wybrane aspekty dotyczące istotnych zmian w doborze materiałów w przemyśle samochodowym.