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Materials Used in the Automotive Industry

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Abstract

Elaborated shapes of many car components are the reason for which the use of casting techniques to fabricate them is a solution well-founded from the economical point of view. Currently applicable regulatory requirements concerning emissions of exhaust fumes force the carmakers to reduce the overall weight of their products, as this is a basic precondition for reducing fuel consumption. As a result, newly launched car models contain a continuously increasing share of thin-walled castings made of materials which ensure a satisfactory level of service properties. At the same time, developing new technological processes allowing to extend the service life of individual components by means of surface improving becomes more and more important.

Keywords: Automotive industry, Materials

1. Introduction

Decisions on selection of materials from which individual automobile components are to be fabricated are made not only in view of the given part operating conditions, but also with economic realities taken into account. Further, requirements concerning environment protection must be also met, and carmakers are under constant pressure to reduce fuel consumption in their vehicles in order to cut down harmful emissions and to use recyclable materials to a largest possible extent.

On the other hand, car users demand increased driving comfort and safety and continuously expect launching new models that should be therefore manufactured in short series. Meeting all these requirements is a challenging task as some of them are mutually exclusive. To improve driving comfort, it is necessary to install additional insulation materials allowing to reduce noise level, introduce many new components and devices such as, for instance, heating systems for door mirrors and driver/passenger seats, or power operated tailgates and other movable components. Improvement of driving safety involves the necessity to reinforce the car body, the braking system, and the tracking system. As a consequence, the motor car becomes more sophisticated, but its weight inevitably increases which in turn leads to higher fuel consumption and more emissions of exhaust fumes.

In view of the above, the manufacturers strive to reduce the total mass of their vehicles by developing new solutions in which particular emphasis is put on the use of thin-walled structures made of alloys characterized with exceptionally good mechanical properties and increasing content of components made of lightweight materials. For instance, studies on the Austempered Ductile Iron (ADI), which is an isothermally hardened spheroidal graphite cast iron, allowed to obtain a material with tensile strength R_m amounting to 1600 MPa at elongation A5 of up to 1%, with the elongation increasing up to 10% at R_m = 800 MPa [1]. This in turn allows to develop designs of thin-walled structures service properties of which can be better then those demonstrated by structures made of lightweight alloys, such as aluminum alloys, with keeping the component weight at the same level. Such cast iron is more resistant to abrasive wear and has better vibration damping properties. It offers also some advantage compared to other materials as far as indicators characterizing the costs to be incurred in order to obtain a specific mechanical strength are concerned.

In recent years, new variations of austempered cast irons have been developed. These include the Austempered Gray Iron (AGI) and the Austempered Compacted/Vermicular Graphite Iron (ACI/AVI) [2].

Among new materials which enjoy increasing range of application one can mention composites, metal foams, and materials used for insulation coatings with high resistant to abrasive wear. Materials analyses indicate that the manufacturers strive after reduction of the cost of manufacturing by using traditional materials and thin-walled structures. Improvement of service properties of such components are obtained by implementing state-of-the-art technological processes to shape superficial layers of car parts, applying various coatings, and reducing the weight of a component by making it from, for instance, an aluminum alloy instead of cast iron. One method of ensuring high local resistance to abrasive wear consists in providing lightweight structures with cast-in elements made of cast iron, steel, or composites. Such processes are counted among high-tech solutions being the subject of interest of numerous scientific and research centers. Their significance for further development of the industry is emphasized in the latest foresights.

2. Materials used in car manufacturing

Metallic materials are responsible for about 80% of the total automobile weight, with the rest contributed by plastics, rubbers, glass, paints, and textiles. The group of metallic materials used by the automotive industry includes steel, cast iron, sintered metals, aluminum alloys, magnesium alloys, metal-based composite materials, and various ceramic and metallic coatings.

Iron-carbon alloys are used to fabricate section profiles and car body sheets, engine components such as crankshafts, connecting rods, valves, valve seats, camshafts, face gears and pinions, connector bodies, fuel tanks, drive shafts, flywheels, pulleys, bearing half-liners, piston rings, gearbox selector forks, exhaust manifolds, rear axle casings, differential gear casings, wheel hubs, and control arms [3–7].

In new-generation combustion engines, sintered metals are used for valve seats. They have much better performance properties compared to steel valve seats. Test-based studies proved that particularly favorable properties can be attributed to valve seats made according to a Polish patent [6]. The sintered seats contain carbon, cobalt, molybdenum, nickel, chromium, magnesium, titanium, and zinc stearate as a lubrication agent.

Aluminum alloys are used for car body frames, door structures, clutch housings, pedals, steering wheels, gearbox housings, cooling system components, pump housings, ignition system components, engine frames, cylinder liners, engine cylinder heads, manifolds, engine brackets, wheel rims [7–10]. The share of aluminum alloys among all the materials used to make car components continuously increases, which has a favorable effect consisting in reduction of the overall mass of a car. There are foresights claiming that within the next few years, the share of aluminum alloy castings in automobiles will double, mainly at the expense of reduced share of components made of steel and cast iron.

In view of the common trend to reduce the total car weight, magnesium alloys are particularly promising materials for automobile parts. Components fabricated nowadays from magnesium alloys include steering columns and wheels, brake and clutch pedal brackets, seat frames, engine frames, transmission gear housings, blower and fan casings, members, dashboard plates, and wheel rims [11–12]. Currently, the highest share of parts cast from magnesium alloy can be found in racing cars. In Porsche 917, for instance, the total weight of components made of magnesium alloys is 133 kg [13], compared to about 25 kg in currently manufactured VW and AUDI car models. It is forecasted that the latter figure will increase up to 87–124 kg within the next five years, and to 132–178 kg [14] in the next decade.

From among a large group of composite materials, aluminum alloys reinforced with silicon carbide or aluminum oxide have been used in the motor car making industry [15–17]. In composites, both the reinforcement phase and the matrix maintain their original physical and chemical properties but together they produce a combination of mechanical features impossible to obtain when component materials are used separately. In case when two or more reinforcing phases with different morphologies are present in the composite structure, one deals with the so-called hybrid composites. Mechanical strength properties and resistance to abrasive wear of composites at elevated temperatures are much better than corresponding properties of alloys without reinforcing additives. In the automotive industry, aluminum composites are used to manufacture engine pistons. Traditional pistons of aluminum-silicon alloys are also fabricated, but with seats for piston rings performed as cast-in elements made of a aluminum composite reinforced with aluminum oxide particles. Such piston introduced in 1982 by Toyota Motor Company was probably the first ever industrial application of metal composites to construction of combustion engines. The use of this particular materials technology allowed to increase significantly the service life of combustion engine pistons. In case of the newest generation of engine frames made of aluminum alloys or magnesium alloys, composite cylinder liners have been used [18]. These cylinder liners are made of an aluminum composite reinforced with silicon particles having specific dimensions. The technological process used to manufacture such cylinder liners is patented under LOKASIL trade mark. LOKASIL cylinder liners are mounted, for instance, in Porsche Boxter sports car. In this materials solution, about 3-mm thick composite cylinder liners have replaced the conventional cast iron liners or aluminum liners with cast-in sleeves made of cast iron. Composite materials were also used to manufacture brake disc and brake drums [19].

It is forecasted that car designs of the future will make use of a wide range of metallic porous materials known also as metal foams, currently fabricated mainly from aluminum alloys. They are characterized with low coefficient of thermal conductivity and good vibration-damping properties which makes them particularly useful as insulation and sound-absorbing materials. For this reason, the metal foams seems to be good potential candidates for car body components. In view of their energy-absorbing properties, they are also considered as materials suitable for car bumpers. Studies in industrial application of aluminum foams are carried out by such corporations as Jaguar Cars Ltd., Ford Motor Company, and Rover Group, to name only a few.

The role of surface coatings applied to automobile components is to mitigate the effects of high temperature and thermal shocks, as well as improve resistance to abrasive wear. The first of the task can be accomplished by using ceramic coatings, while metallic coatings are more suitable for the second purpose.

One of most important targets assumed in studies on new combustion engine design solutions is to obtain as high efficiency as possible. This means the need to increase pressure and combustion gas temperature. To solve the related problems, insulation coatings have been developed for piston crowns. Such coatings allow to reduce temperature of piston crowns in the course of engine running cycle by 50–80°C which translates into extended service life of the piston-liner assembly.

In view of the fact that the coefficient of thermal expansion for ceramic materials is significantly higher compared to this characterizing aluminum alloys, special techniques for application of such coatings has been developed with the use of a transition buffering layer in order to avoid crushing of the coating particles of which would be capable to damage bearing surfaces of both cylinder liner and piston rings. The material of the buffer layer is an alloy containing nickel, cobalt, iron, and aluminum as well as yttrium, hafnium, and ytterbium. The coefficient of thermal expansion for such material has a value close to this characterizing a ceramic coating. A 0.1–0.2 mm thick buffer layer is applied by means of plasma spraying. The actual thermo-insulating ceramic layer, 0.1–0.5 mm thick, comprises zirconium oxide stabilized with yttrium. Ceramic coatings are also applied by means of plasma spraying.

Chromium-based coatings are used on working surfaces of the piston rings/cylinder bearing surface system. Such coatings show high hardness reaching about 1000 HV and good resistance to abrasive wear. It has also good corrosion resistance. Thanks to low value of the coefficient of friction characterizing the contact with cast iron or composite cylinder liner, relatively small amount of heat is released. One flaw of chromium coatings is their poor wettability with oil which creates the risk of seizing in case of large contact surface areas. To eliminate this inconvenience, a technology of applying a porous chromium layer was developed. Chromium coatings are deposited electrochemically. Depending on the piston ring type, depth of the layer ranges from 0.06 mm to 0.25 mm. Surface of the chromium coat should be characterized with absence of any protrusions which could be capable to scratch the cylinder bearing surface.

The wear products occurring in the course of piston ring operation include small particle of metallic chromium. They are pressed into the cylinder liner bearing surface extending thus its service life.

According to some authors [19], chrome plating of cylinder bearing surfaces for engines subject to heavy thermal load and operating in dusty environments does not guarantee that the required durability will be obtained.

It follows from technical material published by KS Aluminum AG [20] that the latest generations of engines mounted in certain car models manufactured by Mercedes-Benz, Porsche, BMW, and AUDI are equipped with aluminum-silicon alloy cylinder liners inner surfaces of which are chrome-plated.

New engines mounted in cars manufactured by BMW and Jaguar are provided with NIKASIL cylinder liners [21]. They are made of an aluminum-silicon alloy with their load-bearing surfaces provided with a coating based on nickel matrix. Such coating. apart from a nickel base, contains also silicon carbide particles with dimensions in the range 2–5 μm. To fabricate such coating, a special technological process involving electrolytic deposition is used. After completion of the honing prcoess, depth of such reinforced nickel coating on NIKASIL liner is 0.06–0.08 mm.

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