Problems and Perspectives of Implementation of Metal-matrix Composition Materials in Automotive Industry

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Abstract. In this paper we studied possible problems and perspectives of deployment of aluminum-based composite alloys in automotive industry. Aluminum-based composite alloys thanks to their high elastic strength combined with a relatively low mass density, good casting and tribological properties with respect to conventional alloys were implemented in automotive industry over 20 years ago already. These alloys successfully substitute steel, cast iron and titanium alloys in engine, suspension, braking units. However high final cost of auto-components made of strengthened aluminum alloys limits its applications in the industry. In this work we presented the examples of aluminum-based composite alloy technology that reduces the production costs of final product.

1. Introduction

A great number of papers deal with the problem of the use of various materials in the automotive industry with due regard to the basic principles (economic feasibility, safety, maintainability) [1 - 5]. The increasing use of aluminum alloys is currently noted in the engineering. This trend is particularly noticeable in the automotive industry. It is associated with striving for decreasing the weight of vehicles and reducing thereby the fuel consumption and for attaining some additional economic and environmental effects. It is known that half the mass of the entire vehicle is constituted by the body weight, so the reducing of the body weight is an effective method for decreasing the weight of the whole vehicle. In the automotive industry aluminum had been used since the end of the 19th century. At the Berlin Exhibition 1989 the Durkopp concept car was shown and three years later the first aluminum engine was presented. Both aluminum casting and deformable alloys are widely used in vehicles. Aluminum casting alloys are mainly used for an engine, a transmission and for suspension components, while deformable alloys are widely used as sheets and pressed profiles in the body structure. The use of aluminum in the automotive industry constitutes currently a major portion of the world-produced aluminum consumption.

The first serial manufacturer of car bodies from aluminum alloys was Audi, which in 1993 introduced the Audi ASF concept (Audi Space Frame) and in 1994 it started the serial production of the AudiA8 sedan; it was the world's first mass car with a fully aluminum body. Motor vehicles Audi (A2, TT, Q7), Jaguar XJ, Hyundai Tibuton / Coupe, Porsche Boxter / Cayman etc. have also partially or completely aluminum body shells. As for tonnage, the largest quantity in ground facilities is implemented in armored vehicles: M113, M2 Bradley, BMD, BMP-3, AMX-10P and others.
Nevertheless, it is currently not always possible to achieve the required level of parameters due to the use of conventional metal materials mainly because of their incompliance with new higher requirements to strength, stiffness and wear resistance. Therefore, metal-matrix composite material (MMC) find the ever-growing application in the automotive industry as they are distinguished by their higher hard-wearing, high resistance to crack generation, the lower coefficient of linear thermal expansion, improved strength characteristics, heat resistance and thermal conductivity. Furthermore, in some cases the product repairability is limited.

Aluminum alloy-based MMC armored by Al₂O₃ provide superior mechanical and physical properties. These composites have the improved physical and mechanical properties, in particular, lower density, low coefficient of thermal expansion, good corrosion resistance, high tensile strength, high stiffness, high hardness and wear resistance. However, the cost of aluminum-based MMC is high. So, today only single parts are widely used as distinct from the aviation. MMC with armoring particles of Al₂O₃ has an improved complex of mechanical and functional properties of the material. In particular, it is possible to increase the hardness by 50 to 75% and the tensile strength by 25 to 50% as compared to pure aluminum. It is shown in [7] that the use of high-energy grinding of the Al-Al₂O₃ mixtures enables to achieve about the 92% increase in hardness and the 57% increase in the tensile strength of the composite as compared to pure aluminum. So, the results of the study of various versions for sintering powders of aluminum alloys with SiC and Al₂O₃ are shown in Ref. [8, 9]. It is also shown in Ref. [10 - 12] that the MMC corrosion resistance is higher than that of classical alloys.

![Figure 1. Usage of particulate reinforced materials. [6]](image)

In the automotive industry MMC substitute steel, cast iron, titanium and copper alloys due to a complex of mechanical properties.

MMC are mainly used in the following vehicle components:
- Engine: The substitution for steel and cast iron enables to obtain the increased stiffness, wear resistance (hardness) and in some cases, enhanced fatigue strength. Such typical applications are Toyota and Honda engines (Fig. 2). Ref. [5] shows the examples of the implementation of aluminum alloys for pistons to diesel engines and internal combustion engines in the CIS countries.
- Braking system: The MMC high wear resistance and high thermal conductivity make it possible to substitute cast iron and steel in disc brake rotors and in brake drums, thus reducing the weight to 60% (Fig. 3). The paper [6] describes the history of the MMC application in automobile brake systems. The typical examples of the MMC use in brake systems are Volkswagen, Audi, Toyota vehicles.
- Driveshaft: The MCC use for cardan shafts enables to achieve higher rigidity. So, MMC enable to manufacture longer cardan shafts as compared with steel ones while preserving the same diameter and mass. A cardan shaft made of 6061/Al₂O₃ by the extrusion method is shown in Fig. 4.

According to available literary references MMC are currently produced in various ways: by precipitation of particles from a supersaturated solution (dispersion-hardening alloys), by powder metallur-
gy method including mechanical alloying [13, 14]. Table 1 shows based on the data of [15] the effect of powder components, Al₂O₃ and SiC on the mechanical properties of a resulting alloy.

**Figure 2.** Partial short fiber reinforced light metal diesel pistons.

**Figure 3.** Cast brake disk particle of reinforced aluminum.

**Figure 4.** Al-Al₂O₃ extruded driveshaft.

**Table 1.** Effect of Powder Components, Al₂O₃ and SiC on the Mechanical Properties of a Resulting Alloy.

| Alloy                        | Yield stress (MPa) | Tensile strength (MPa) | Young’s modulus (GPa) |
|------------------------------|-------------------|------------------------|-----------------------|
| 6061-T6 (Cast prematerial (extruded or forged)) | 355               | 375                    | 75                    |
| 6061-T6 + 20% Al₂O₃         | 365               | 405                    | 95                    |
| 6061-T6 + 20% SiC           | 397               | 448                    | 103,4                 |

It should be noted that with a less increase in mechanical properties Al₂O₃ has a lower cost as compared to SiC. However, the significant reduction in the MMC production cost may be achieved by changing over to alternative composite production versions. In [16] a method is described for producing an Al-Al₂O₃ composite material by plastic deformation and in [17] a method for fabricating aluminum nitride particle-saturated MMC by the reaction of Al₂O₃ + 3C + N₂ → AlN + 3CO. Ref. [18] contains information concerning the method of fabricating ceramic composite Al₂O₃-AlON-AlN, in Ref. [19] the process of aluminum melt blow-down with water vapor to produce light deformable highly-silica alloys is described; in Ref. [20] the method of the Al-TiC composite production by the titanium carbide synthesis directly in melt with hydrocarbon containing gas into molten Al-Ti. There have also been developing other technologies.

The most typical example of decreasing the MMC production cost is the internal oxidation technology [21, 22]. The cost of raw materials is reduced because of the withdrawal of powdered components and their substitution by blowing down with oxygen containing gas. Aluminum oxide is produced by the following reaction

\[ \text{Al} (1 \text{ g}) + \text{O}_2 (0.9 \text{ g}) = \text{Al}_2\text{O}_3 (1.9 \text{ g}) \]

In Tab. 2. Gives for comparison the cost of producing an aluminum alloy saturated with 30% Al₂O₃.

The aluminum price varies from USD 1.2 to 3.3 depending on the brand and delivery status; the price of Al₂O₃ is from 5.6 to 83 USD/kg depending on the particles purity and size, the price of oxygen is from 1 to 2.5 USD /m³ depending on the purity.
Table 2. Comparison the Cost of Producing an Aluminum Alloy Saturated.

| Option 1 introduction of powdery Al₂O₃ | Option 2 internal oxidation |
|----------------------------------------|-----------------------------|
| 0,7 kg Al (1.6 USD/kg)                 | 0,86 kg Al (1.6 USD/kg)     |
| 0,3 kg Al₂O₃ (16.6 USD/kg)             | 0,15 kg O₂ (1.6 USD/m³)     |
| cost is 1 kg of alloy of 6.1 USD/kg    | cost is 1 kg of alloy of 1.8 USD/kg |

2. Conclusion

Aluminum-based composite alloys thanks to their high elastic strength combined with a relatively low mass density, good casting and tribological properties with respect to conventional alloys were implemented in automotive industry over 20 years ago already. However the major factors limiting the stretching use of connections is the cost of production and the increasing expenses for their production. The elaboration of alternative cost-effective technologies for the MMC production will significantly expand the scope of the MMC application in the automotive industry.

3. References

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