

## Future in Metal Matrix Composites for Automotive Industry:

### A Review

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### ABSTRACT

Automobile industries are mortal focused to progressively more stringent fuel financial system desires, whereas patrons are challenging enhanced internal comforts and sophisticated electronic systems for protection, routing, and amusement, all of which add otherwise redundant weight. To meet these challenges, automotive makers are turning to light-weight metals as an answer. Strict needs that are placed on mechanical constructions from the side of increase of exploitation periods and reduction of their weights, therefore of their prices as well, implicate developments and applications of latest composite materials with matrices of light-weight metals. Composite materials with metal matrices are used for engine cylinders, pistons, disc, and drum brakes and for other elements in the automotive and aviation industry. The most important type of metallic materials is composite materials with matrices of aluminum alloys due to a set of their beneficial properties. Improvement of mechanical, especially tribological properties of hybrid composites were provided by the use of certain reinforce materials such as SiC, Al<sub>2</sub>O<sub>3</sub>, and graphite in defined weight or volumetric share. New developed hybrid composites with aluminum matrices have significantly higher resistance to wear, higher specific stiffness and higher resistance to fatigue. By the increase in quantities of produced elements made of hybrid composites, a decrease in their prices is induced that even further enlarge their applications. The applications of aluminum hybrid composites are considered from the aspect and with the focus on the automotive industry.

**Keywords:** MMCs, Aluminum alloy, Automotive, Wear resistance, High strength, brake, piston and cylinder.

### 1. INTRODUCTION

Automakers are being subjected to increasingly strict fuel economy requirements, while consumers are demanding improved interior comforts and advanced electronic systems for safety, navigation, and entertainment, all of which add otherwise unnecessary weight. To meet these challenges, automotive manufacturers are turning to lightweight metals as a solution[1-3]. Aluminum engine blocks, suspension components, body panels, and frame members are increasingly common, in addition to the use of magnesium in components such as instrument panels, valve covers, transmission housings, and steering column components. Combining or replacing these efforts with the use of advanced metal matrix micro- and nano-composites (MMCs) not only reduce mass, but can also improve reliability and efficiency [4,5]. Composites, as relatively new materials, still do not have a generally accepted definition. Composites are made by compounding of two or more different materials. Their basic constituents have own different characteristics and properties, while the compound presents a completely new material. This material has its own unique, completely new and different properties in relation to constituent components. The aim of this material compounding is to improve structural, tribological, thermal, chemical or some other material properties. Constituent components do not mix and dissolve between each other, so two or more phases are present within composite material [6, 7, 8].

Aluminium is the world's most abundant metal after iron. This is the third most common element comprising 8% of the earth's crust. The versatility of aluminium makes it the most widely used metal after steel. Aluminium is derived from the mineral bauxite. Bauxite is converted to aluminium oxide (alumina) via the Bayer Process. All the alumina used by the market economy aluminum industry is manufactured by the Bayer process, the basic features of which have remained unchanged since Karl Josef Bayer patented the process in Germany in 1888 [9, 10].

## 2.0 APPLICATION OF MMCS USED IN AUTOMOBILE PARTS

From the aspect that over 50 % of global production of composite material with metal matrices is used in the automotive industry, the focus of application of this material will be put on cars. Large numbers of automobile elements square measure fabricated from composite materials. The ratios of their costs and qualities gift main causes for applications of these materials. It is obvious that composite materials with metal matrices square measure typically used for accountable elements at trendy cars [11-22]. Table 1 shows MMCs used in Automotive applications.

*Table 1 MMCs materials being developed for use in automotive applications*

Property	Materials	Application
Wear resistance	Sic, Al <sub>2</sub> O <sub>3</sub> , graphite-reinforced micro and nano MMCs	Bearing surfaces, cylinder liners, pistons, cam shafts, tappets, lifters, rockers, brake components
Light weight, energy absorption	Fly ash cenosphere – and low-density ceramic microballan-reinforced syntactic foam MMCs	Crumple zones, frame members and reinforcements, pedestrian impact zones, batteries
Self-cleaning	MMCs with hydrophobic reinforcements, biometric coatings, and surface finishes	Water pumps, water jackets, exposed metallic components
Self-lubricating	Micro and nano MMCs incorporating graphite, MoS <sub>2</sub> , TiB <sub>2</sub> , hexagonal BN, or other solid lubricants	Bearing journals, cylinder liners, pistons, cv joints, gear surfaces
Self-healing	MMCs incorporating shape memory alloys or hollow reinforcements filled with low-melting healing agents	Difficult-to-access, fatigue prone, and critical components, such as driveshafts, wheels, steering knuckles and columns, and connecting rods
High thermal conductivity	Micro and nano MMCs reinforced with high conductivity carbon, diamond, or cubic boron nitride (cBN) powder	Cylinder liners, water passages, brake components, turbo/supercharger components, catalytic converters, electronics packaging
High strength	Micro and nano MMCs reinforced with SiC or Al <sub>2</sub> O <sub>3</sub> particles, carbon nanotubes (CNT), carbon or Nextel fibers, and in-situ ceramics	Connecting rods, brake calipers, brake rotors, brake calipers
Low cost	MMCs containing fly ash or waste sand as fillers	manifolds, accessory brackets, low-load brackets, oil pans, valve covers, alternator covers, water pumps

## **2.1 Pistons and cylinder liners**

Engine pistons operate in very hard dynamical, thermal and mechanical conditions. The pistons are loaded to cyclic mechanical load with the frequency of around 100 Hz, so fatigue damages are primarily important. Pistons must provide intimate contacts with cylinders at maximal pressures during expansion periods. Dynamic endurance, high resistance to wear and thermal expansion coefficient are necessary characteristics of materials for cylinders. It is also necessary that pistons can operate at temperatures of around 3000 °C. Due to temperature gradients and thermal cycles, high thermal conductivity must be provided in order to reduce temperatures and thermal impacts. Breakthrough in the area of aluminum MMC application is done by production of pistons for diesel engines at Toyota car manufacturer [23, 24, 25]. The serial production of those pistons started in Japan in 1983. The materials for the pistons were composite materials with aluminum alloy matrices reinforced by ceramic particles and fibers in order to reduce wear and to improve resistance to material fatigue at high temperatures. Those composites were made by squeeze casting method. Due to the large series in a production of over 100.000 items per mount, the produced parts had excellent quality at satisfactory prices. Metal matrices composites with ceramic reinforcements used for the production of pistons have significantly higher resistance to wear in relation to materials used for matrices. Simultaneously, pistons have small values of thermal expansion coefficients that provide use of narrow tolerances, so that it results in increasing of maximally allowed pressures and improved thermal conductivity properties [24]. Lower weights of pistons also have positive influence to beneficial properties of materials in exploitation. Besides that, a method of MMC casting is quite simpler than the traditional method of piston fabrication. In general, besides higher prices of aluminum materials by units, summary prices of pistons are smaller than pistons made of traditional materials. Large numbers of positive performances of MMC application implicate the use of those materials for pistons made. As reinforcing materials to metal matrices silicon carbide (SiC) is usually used especially at race cars.

The pistons made from MMC square measure wide employed in Asia and West Europe automobile producers (Fig. 1).



*Fig:1 Pistons made of aluminum MMC*

Aluminum engine blocks typically require cast iron cylinder liners due to poor wear characteristics of aluminum. Porsche is using MMCs for cylinder liners by integrating a porous silicon preform into the cast aluminum block, and Honda uses a similar method incorporating alumina and carbon fibers in the bores of die-cast aluminum [26]. These practices improve wear characteristics and cooling efficiency over cast iron liners. UWM developed aluminum alloy pistons and cylinder liners containing dispersed graphite particles that provide solid lubrication [27].

The graphite-containing metallic element contains a lower friction constant and wear rate, and does not seize under boundary lubrication. The liner is cast in a single step using the centrifugal casting process to concentrate graphite particles near the inner periphery where they are needed to provide solid lubrication [27,28]. Aluminum graphite pistons and liners were tested in gas and diesel engines and in race cars, resulting in reduced friction coefficients and wear rates. As black lead shears below wear conditions, it creates an eternal film of black lead on the metallic element and reduces the damage rate of the liner.

The measured friction coefficient of Al-graphite composites is as low as 0.2[27]. Application of this material for cylinder liners in lightweight aluminum-engine blocks enables engines to reach operating temperatures more quickly while providing superior wear resistance, improved cold start emissions, and reduced weight[29]. Aluminum-based composite liners can be cast in place using conventional casting techniques, including sand, permanent mold, die casting, and centrifugal casting.

## 2.2 Connecting rods

By making engine connection rod of aluminum MMC mass reduction of 57 % related to steel one is obtained. By reduction of piston/connection rod mass, vibrations throughout operation are reduced. By that, reduction of a load at the crankshaft and at its bearing is also done, energy losses due to friction are also reduced, the same as engine fuel consumption [30]. It is concluded that reduction of the crankshaft by 1 kg caused related reduction of balancing counterweight by 7 kg [30]. As the material for the making of connection rod, composites with aluminum matrix reinforced by SiC (Nissan) or Al<sub>2</sub>O<sub>3</sub> (Dupondt, Chrysler) are used [31]. By application of aluminum connection rod, reduction of fuel consumption and improvement of engine power are done with the simultaneous increase of its total production cost [32]. Further researches of MMC are focused on the production of materials that can be used for pistons connecting rods. The prototype of connecting rod made of aluminum MMC is presented in Fig. 2. The researches in this area are still in process.



*Fig: 2 Piston connecting rod made of aluminium MMC*



### 2.3 Brakes

Automotive disk brakes and brake calipers, typically made of cast iron, are an area where significant weight reduction can be realized. SiC-reinforced Al brake rotors are incorporated in vehicles like the Lotus Elise, Chrysler Prowler, General Motors EV1, Volkswagen Lupo 3L, and the Toyota RAV4-EV[5]. Widespread use of Al composite brake rotors needs their prices to return down and improved machinability. UWM developed aluminum-silicon carbide-graphite composites, aluminum-alumina- atomic number 6, and hypereutectic aluminum-silicon-graphite alloys with reduced carbide to assist overcome value and machinability barriers. Aluminum-fly ash composites developed at UWM have been explored to make prototype brake rotors in Australia[33]. Aluminum calipers are also used in performance applications because of the weight advantage, but require additional bridging between the two halves of the caliper to increase rigidity. Strength improvements seen in aluminum nano-composites being developed at UWM can provide significant improvements in component rigidity without adding a significant amount of material, resulting in lower weight components. Due to beneficial characteristics, high resistance to wear and high thermal conductivity, aluminum MMC is used for the production of brake discs and drums at cars. On the basis of the weight reductions, inertial forces are also reduced, so as the summary weight of vehicles and fuel consumptions.



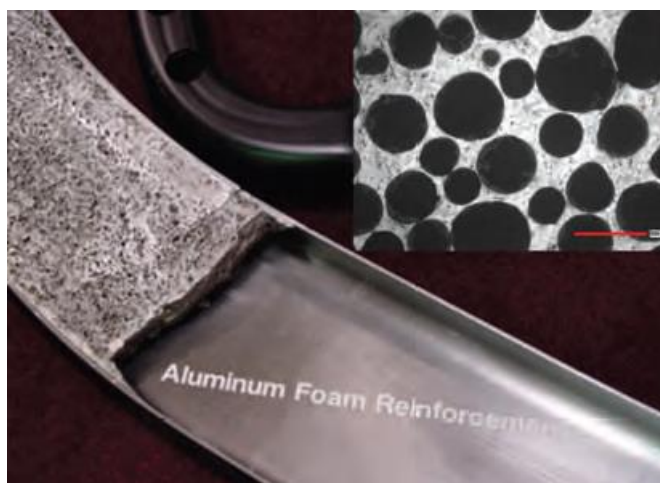
*Fig: 3 Brake systems made of aluminium MMC*

Al-Mg and Al-Si alloys reinforced by ceramic materials such as SiC and Al<sub>2</sub>O<sub>3</sub> are used for the production of brake discs and drums [34-39]. The technology processes for the production of composite materials are different casting methods, while a volumetric share of reinforcing materials is up to 20%. A large number of producers in automotive industry use aluminum MMC for production of brake systems. At Lotus Elise (1996 -1998) all four sets of brake square measure made from MMC. Plymouth Prowler rear sets of brake square measure made from MMC. Uncontinual reinforced aluminum MMC is used for brake discs of Volkswagen Lupo 3L and Audi A2. Hybrid and electrical vehicles are also equipped by brake systems made of aluminum MMC as Toyota RAV4, Ford Prodigy, and General Motors Precept [3, 7, 25]. Brake systems made of aluminum MMC are presented in Fig. 7. Brake discs made of uncontinual

reinforced aluminum MMC are used at high-speed trains in Germany – InterCity Express (ICE). Those brake discs are used at ICE-1 and ICE-2 trains on more than 100 train compositions [5]. Aluminium MMC is additionally used at brake systems of race cars. As materials for brake systems of race cars, Al 2124/SiC/25p is used. Braking pads made from MMC square measure used at Porsche 911. All those composites have ceramic reinforcements.

## 2.4 Chassis

Strength and toughness of the chassis can affect vehicle performance, and also is important to occupant survivability in severe crashes. Hollow ceramic microspheres incorporated into metal matrices end in a grammar foam product, which is about one half as dense as the matrix and is able to absorb large amounts of energy per unit weight upon impact compared to monolithic alloys and open cell foams. Aluminum-fly ash cenosphere grammar foams being developed at UWM (Fig. 4) can be used to reinforce box or tubular frame sections in crumple zones to both increase torsional rigidity for improved vehicle dynamics and increased energy absorption upon vehicle impact[40, 41]. In advanced automotive applications, a syntactic foam can also serve as a core material to increase a rigidity of thin gauge sheet metal sandwich structures, where high-performance materials such as Kevlar honeycomb core material is cost prohibitive.



*Fig: 4 Aluminum-fly ash cenosphere syntactic foam (micrograph inset) within a steel frame.*

## 2.5 Suspension

Many automakers started to use aluminum and light gauge steel for suspension components to reduce unsprung weight and improve vehicle dynamics, but many components are still made of cast iron. Components such as control arms or wheel hubs made of strong silicon carbide(SiC) strengthened atomic number 13 or atomic number 13 nano composites will more improve atomic number 13 alloy stylesby up strength characteristics the same as forged iron whereas victimization less material than similar atomic number 13 arms. Self-lubricating graphite-reinforced atomic number 13 bushings may also be incorporated into control-arm castings to permitfor parts that don't need service and can last the lifetime of the vehicle.

### 3. FUTURE IN MMCS USED FOR AUTOMOBILE INDUSTRY AND OTHER SECTOR

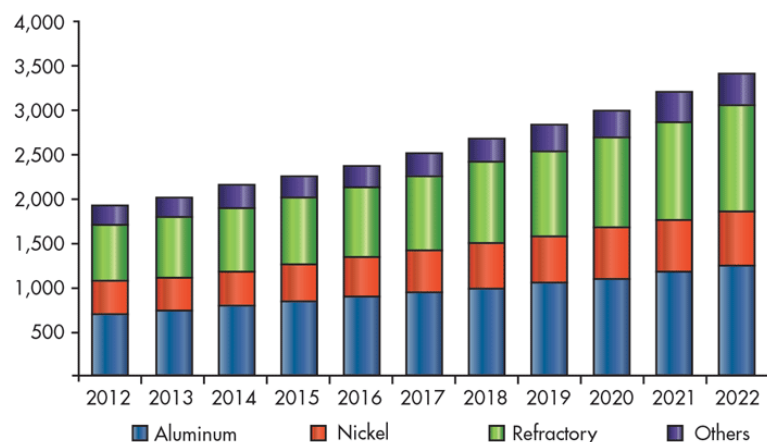
By infusing different materials into metals, scientists and engineers are creating stronger lightweight metals that are being used in a multitude of industries to increase efficiency and performance. MMCs are metals or alloys that incorporate particles, fibers, or hollow micro-balloons fabricated from a special material.

Scientists and engineers have created these superior materials by metals with alternative alloys, ceramic, and other organic compounds in order to improve the properties of standard materials. For instance, aluminum can be reinforced with boron, carbon, silicon carbide, alumina, or graphite to create a composite that is 30% to 40% stronger and more rigid than barebones aluminum. Metal matrix composites break down into four totally different categories: dispersion hardened and particles; layer composites; fiber composites; and infiltration composites.

The design requirement to make products lighter but still maintain their productivity has increased the demand for metal matrix composites (MMCs). These materials square measure getting used during a style of industries, including automotive and aerospace applications.

Manufacturers then utilize these composites to form higher, more stable, and lighter weight products for various industries (i.e., automotive, aerospace, and defense). According to Mahitha Mallishetty, metals and minerals analysts from Technavio Research, “The global metal matrix composites market size is projected to reach 10.8 kilotons by 2021, growing at a CAGR of over 6 June 1944 throughout the forecast amount.” A market report from Grand View Research in 2014 says that the largest product segment was the aluminum-based metal matrix. It accounted for 30% of the demand. The need for light-weight and high lastingness elements square measure the driving factors for the demand of metal to soar. The report predicts that metal can still grow and be the leader of MMCs till 2022.

Refractory matrix metals, metals that contain ceramic material, square measure poised to be the second-largest MMC market by 2022. Their demand can grow because of is multifunctional properties. They can be used for tools, nuclear radiation management rods, solar panels, spacecraft exteriors, and catalysts in chemical reactions. They have a high lastingness, physical property, and ductility.



*Fig: 5 The bar graph above shows the growth trend of different metals used for MMCs until 2022.*

The North America market accounted for over thirty four.8% of the total MMC demand in 2013 and is expected to remain the largest market for 2022. The continued growth within the Asia Pacific can drive the rise of MMC, making it the second-largest marketplace in the world.

Automakers, especially, are increasingly turning to MMCs in order to meet strict fuel economy requirements. The challenge has been to reduce the weight of vehicles without sacrificing consumer demands for comfort and safety. To overcome those obstacles, automakers profit of MMCs' distinctive characteristics, which offer the power to satisfy specific and rigorous style needs. The table 2 shows a survey of the future in MMCs.

Name of the organization	year	Portrayal	Application
Global NdFeB Permanent Magnets Market(42)	2018-2025	The NdFeB Permanent Magnets market worth about X billion USD in 2017 and it is expected to reach XX billion USD in 2025 with an average growth rate of X%. United States is the largest production of NdFeB Permanent Magnets Market and consumption region in the world, while China is fastest growing region.	Electric Motors Instruments And Meters Auto Industry Other
Miltech(43)	2014-2022	With the slowdown in world economic growth, the Metal Matrix Composites industry has also suffered a certain impact, but still maintained a relatively optimistic growth, the past four years, Metal Matrix Composites market size to maintain the average annual growth rate of X% from XXXX million \$ in 2014 to XXXX million \$ in 2017, BisReport analysts believe that in the next few years, Metal Matrix Composites market size will be further expanded, we expect that by 2022, The market size of the Metal Matrix Composites will reach XXXX million \$.	Industry Segmentation (Ground transportation, Aerospace, Electronics and thermal management)
CW(44)	2023-2024	Ultimately, Navistar's Oppermann says, a major transition in the long-haul truck market to composite materials will have to wait until the next generation of trucks is created, which for the long-haul industry is in the 2023-2024 timeframe. "To make the business case, we have to do it at the system level. The entire cab has to be designed that way," meaning a purpose-built design from the ground up. In heavy trucks, says Oppermann, "that happens only every 15 years."	heavy trucks and trailers
Tactical Business(45)	2025	The increasing demand for chemical vapor deposition in fabricating materials produced by metal matrix composites and ceramics is likely to the support the growth of this market in the years to come, states the research report. The microelectronics application segment accounted for the largest share of the market and is estimated to reach USD 30,789.90 million by the end of	microelectronics, cutting tools, medical devices & equipment, industrial & energy, decorative coating, electrical & electronics,



		2023. Yet, the medical device & equipment segment is estimated to grow at the highest CAGR of 7.28% due to rising spending on health by both government and masses due to growing health awareness.	automobile, and others.
Green energy 24(46)	2017-2023	Global Metal Matrix Composite market registered USD 489.1 Million in 2017 and projected to hit USD 713.67 Million by 2023, with a CAGR of 6.50% throughout 2018-2023. This Metal Matrix Composite report covers the statistics for enterprise contest blueprint, business strategists, advantages, and pitfalls of enterprise services and products cost and revenue of the vendors effective within the Metal Matrix Composite market. To figure out the industry dimensions, the Metal Matrix Composite report believes the revenue generated by supplier analysis worldwide. Evolving dynamics and Metal Matrix Composite market trends, opportunity mapping together with inputs from industry pros concerning technological discoveries together.	Ground Transportation Thermal Management Aerospace Industrial
Technavio for metals and minerals research(47)	2021	The global metal matrix composites market size is projected to reach 10.8 kilotons by 2021, growing at a CAGR of over 6% during the forecast period. The use of metal matrix composites in the manufacture automotive components is one of the key drivers of the market	ground transportation, electronics and thermal management, and aerospace), and geography
Open PRworldwide public relations(48)	2023	The rising growth of the construction and automotive industry across the globe is substantially affecting the growth of the functional composites market. Global Functional Composites Market 2018 to 2023 focus on business Intelligence for revenue-generating processes, market research future illustrated some of the typical ways that is used to improve key revenue generation processes. Fundamentally, Functional Composites market analysis, new technology, scope, stake, progress, trends and opportunities are about using detailed and specific business information about client.	automotive, building, and construction, aerospace, and defense.
ID Tech Ex(49)	2017-2027	A composite part consists of fibres embedded in a matrix to give superior properties in comparison to their individual elements. This report provides the most comprehensive global view of this market with detailed sections,10-year forecasts, and application trends segmented for each synthetic and natural fibre in a polymer, metal, or ceramic matrix.	

#### **4. CONCLUSION**

It is obvious that the present development of industry is coupled with the necessity for the application of lightweight materials with beneficial mechanical and tribological characteristics that can fulfill technical and technological requirements. One of the best-suited material with characteristics that can provide most of the modern demands is aluminum and its alloys. But, aluminum, as well as some of its alloys, has proper tribological and mechanical properties only as for constituent of composites. The common reinforcing materials of metal matrices composite materials SiC and Al<sub>2</sub>O<sub>3</sub>.

Applications of aluminum and composite materials with aluminum base provide design and produce high-performance vehicles with safety improvements and improvements of energy efficiency and ecology aspects that are resistant to corrosion and with reduced masses. Composites with the aluminum base are usually used for making of engine pistons, cylinders barrel, connection rods, elements of vehicles braking systems, and so on. By the application of aluminum at the vehicle body, indirectly an increase of engine lifetime is done, the same as an increase of lifetime of the gearbox, breaking system, wheels, and other vehicle systems.

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