Materials Today: Proceedings 26 (2020) 2419–2424

Contents lists available at ScienceDirect

Materials Today: Proceedings

journal homepage: www.elsevier.com/locate/matpr

# A study of advancement in application opportunities of aluminum metal matrix composites

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ARTICLE INFO

*Article history:*
Received 7 January 2020
Received in revised form 17 January 2020
Accepted 13 February 2020
Available online 13 March 2020

*Keywords:*
Composite material
Metal matrix composite
Aluminum metal matrix
Applications
Aluminum

ABSTRACT

Materials are continuously developed with the time being due to the necessity of human civilization and therefore advancement of each material in its highest classes is the best research necessity. The search for new and advanced materials is always an important subject for contemporary technological requirements and to make a product at optimum cost which is a basic consumer demand. New materials are continually developed and materials properties improved in line with existing technological developments in order to meet safety and operational standards. Composites have developed continuously from its early to the advanced stages. The need and consumption of metal matrix composites (MMCs) continuously increasing worldwide with the time because of its high applications. A continuous need observed in industries which make the path to develop stronger lightweight material which having high efficiency and performance across a wide variety of industries. The product manufacturers are generally in need of lightweight, medium strength and less cost, for them aluminum metal matrix composites (AlMMCs) is an asset. AlMMCs for many engineering applications are seen as new generation potential materials. AlMMCs offer great promise for producing composites with the required properties for certain applications with a wide variety of reinforcing materials. The AlMMCs are evolved to obtain good mechanical and tribological characteristics with lightweight, based on specification and application requirements. In this article, various aspects and analysis of applications fields of AlMMCs discussed in brief.


## 1. Introduction

In most instances, the choice of materials for different applications is tough, lightweight materials are mostly having less strength while brittle materials having less toughness and fatigue resistance. The search for new and improved materials remains constant, along with modern technological demands for devices and machinery more energy-efficient, more durable, lightweight, cost efficient etc. Finding a single monolithic material for engineering applications with the necessary property profile is almost impossible. Two or even more materials should thus be combined, such as alloys or composites, to obtain the various useful properties of various materials and can be used for most engineering applications and in very few applications generally pure monolithic materials used [1].

## 2. Composite materials

Composite materials are those materials which are comprised two, or even more, elements with different physical, chemical and mechanical properties and are chemically different from each other, yet exhibit a single material property. By producing composite materials, it is possible to acquire certain characteristics which cannot be achieved when each of the constituting materials is used individually. Consequently, a new material with the required properties for the desired application field can be developed and produced. Composite materials are being used increasingly in

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https://doi.org/10.1016/j.matpr.2020.02.516
2214-7853/

industrial applications because of a variety of reasons such as high strength, excellent thermal properties and exceptional mechanical properties such as fracture toughness, wear and corrosion resistance. Usually composite materials are produced through the distribution of one or even more discontinuous phases generally referred to as a reinforcement material or reinforcing material in a continuous phase which known as a matrix. The reinforcement material possesses much better properties than the matrix materials, the matrix material is intended to hold reinforcements together and preserve the formal integrity of the material and it creates the primary structure of composites [2].

The reinforcement material is generally used to enhance the desired characteristics of the matrix material. The mechanical characteristics of the composite material are determined by different factors, which includes the properties of the matrix and reinforcement materials, the characteristics of the bonds between the matrix and reinforcement materials, the volume ratio of the matrix and reinforcement materials, the orientation, structure and shape of the reinforcement material within the structure of composite. In the composite material, the matrix and the reinforcement phase, which are essentially insoluble in each other, must not dissolve in each other, but extremely low solubility can positively influence the formation of a strong bond between the matrix and the reinforcement. The structure and characteristics of the matrix-reinforcement interface significantly affect the composite material's mechanical and physical properties. Composite materials can be classified in different types, on the basis of the different type of materials used as the matrix in the composites can be divided into three main types as polymer, ceramic and metal. Polymer matrix composites (PMCs), ceramic matrix composites (CMCs) and metal matrix composites (MMCs) produces by the addition of reinforcement into these Materials [3].

## 3. Metal Matrix Composites (MMCs)

MMCs are most commonly used in industrial applications due to their advantages in comparison PMCs and MMCs. Compared with PMCs, MMCs have many excellent physical, mechanical properties which are not found in polymer matrix composites such as its high strength and stiffness, wear resistance, dimensional stability, capacity to withstand at higher temperatures excellent thermal and electrical conductivity. The MMCs obtained a remarkable place in high tech research and applications from the first development to present time and has shown great potential in the aerospace, automotive, military applications, electronic instruments and in other industries. The most important feature of MMC is that the properties according to specific needs can be obtained which make it different from other materials. MMCs are due to high advancement, possess a high application in various areas. MMCs have widely been recognized for excellent performance improvements over traditional materials [4].

The important factors in the determination of the application of a material are cost in addition to performance. In a specific manufacturing process, the cost of raw materials is not deciding the overall performance of the material, but it also depends on the fabrication process of product. The need and consumption of MMCs continuously increasing worldwide with the time because of its high applications. In the various fields of applications, like electrical, construction, electronic and automotive sectors, the MMCs are growing and anticipated developing in the near future. Nevertheless, a great development is expected in these composites and their advancement would contribute to a growing increase in their applications. A very high percentage of the global production of MMCs is used in the automotive industry, Due to their price and excellent properties. Previously, MMC have had disadvantages of their costs and lack of experience of use, but the final cost of MMC components can be reduced due to significant developments in the manufacturing routes [5].

## 4. Aluminum Metal Matrix Composites (AlMMCs)

Aluminum is one of the most popular and common metal. Aluminum is simple to handle, lightweight and having good corrosion resistance, high strength as well as its economical manufacturing possible through many methods of production. Successful processing and commercial applications of aluminum started in the 19th century. It is a relatively cheap material. Worldwide Primary aluminum production in the last few years shown in Fig. 1. To make this graph the data collected from the website of international aluminum institute, United Kingdom. Aluminum having the high specific strength but Performance at high temperatures is not satisfactory because of low melting temperature, it has a very good


**Fig 1.** Primary Aluminum production globally from 2009 to 2019.

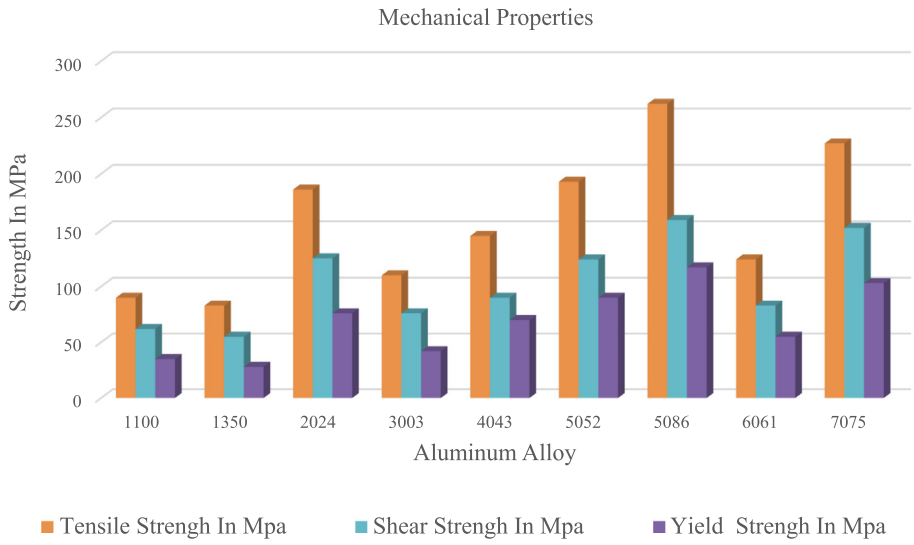


**Fig 2.** Comparison of Shear Strength Values, Yield Strength Values and Tensile Strength Values of Wrought Aluminum alloys (annealed).

thermal and electrical properties, but low hardness and very low wear resistance. Aluminum and its alloys most widely used as the matrix material in manufacturing of MMCs. To enhance the existing properties of aluminum and its alloys, reinforcing materials generally used, so the tensile strength, melting temperature, thermal stability and mechanical characteristics generally improved. Aluminum alloys can be divided as wrought and cast alloys, the wrought alloys having a 4-digit system (xxxx) for identification. The first digit show principle alloying element. Various mechanical properties, including shear strength, yield strength, tensile strength and hardness of wrought Aluminum alloys (annealed) of the different series shown in Figs. 2 and 3. The research in the field of aluminum matrix composite materials began near about in the middle of the 20th century. In the past years to till date both theoretical and technical research have been done worldwide. Countries have invested a lot of manpower and resources in research and development. It is the most studied, researched, common and important composite material in metal matrix composites [6,7].

In the manufacturing of composite materials, aluminum possesses lots of characteristics, including lightweight, low density and simple to process. AlMMCs having excellent characteristics like other composite materials to fulfill customer requirements. Aluminum have consequently turned into one of the frequently used material in metal matrix composites. Study shows that AlMMCs are an important substitute for better performance and longer life in comparison to other conventional metals. In automotive engineering, the spectrum of applications for lightweight materials is increasing, yet these must work under ever more punitive circumstances at the same time. The solution of this is to use reinforced lightweight materials with advanced ceramic to improve thermal, mechanical and tribological characteristics, by the use of reinforcement, creation of a completely new super class of composites is possible which can be used in new range applications even in areas that were unable to utilize formerly developed composite until now [8].

In case of reinforcing and optimizing lightweight metallic materials, the use of Metal Matrix Composite is a highly attractive option for both engineering and many other industrial applications. Types of reinforcement materials having a significant role in the selection of fabrication techniques of AlMMCs. The reinforcement particles which generally used are SiC, Si3N4, Al2O3,

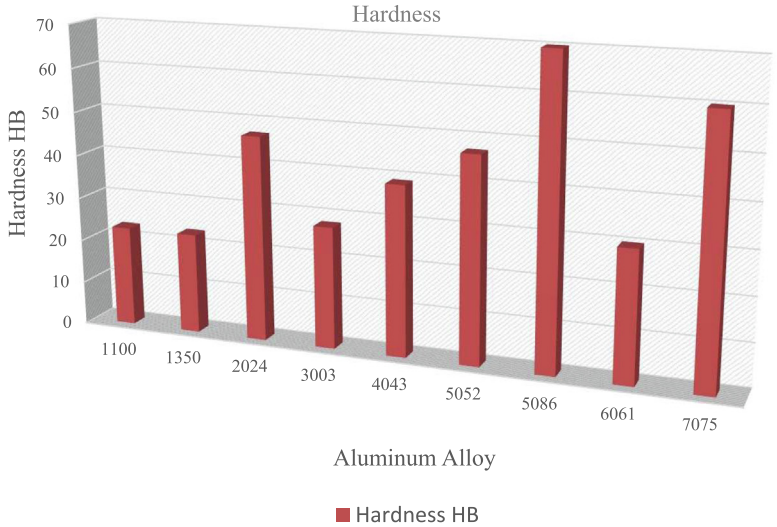


**Fig 3.** Comparison of Hardness Values of Wrought Aluminum alloys (annealed).

TiC, TiB2, B4C, graphite and metal particles Different research activities have been carried out continuously to tackle the key problems and hurdles including the development of new solutions for cost reduction in AlMMCs manufacturing and the enhancement of properties like wear corrosion. The AlMMCs possesses good specific strength, rigidity, fatigue strength, resistance to wear and low thermal expansion coefficient. AlMMCs are extremely encouraging for the number of potential industrial applications [9].

## 5. Applications of AlMMCs in various industries

Because of their high strength, low cost and weight, AlMMCs are potentially popular materials in many industrial applications and automotive field. AlMMCs possess good characteristics in the comparison of traditional materials, which includes, excellent mechanical properties and having extremely vast applications in aviation, mechanical, electrical, automotive, electronics and transport industries. The different application areas of AlMMCs shown in Fig. 4 [10].

The applications of AlMMCs shown in Fig. 4, are given below in the elaborated manner.

### 5.1. Automotive industry

Most of today's metal matrix composites are focused on aluminum and alloys for automotive applications, mostly in engine parts, piston, connecting rods and Piston pins. MMCs are typically used to reduce the mass of reciprocating components in the manufacture of automotive engine and therefore create less noise and vibrations. The main factor for widespread use of aluminum in automotive alloys in comparison of other lightweight materials, such as titanium and magnesium, is lightweight and low cost. Leading automotive manufactures started use of AlMMCs commercially due to enhanced wear resistance, strength thermal properties, lightweight and inexpensiveness. MMCs used in the manufacturing of the valve and lightweight brake calipers. The emphasis of the usage of AlMMCs generally centered on vehicles. Research study on AlMMCs in the automotive sector began at the earliest [11].

A Japanese firm Toyota in the 1980 successfully made piston ring for the engine used in the automobile, connecting rod for the car and other parts by reinforced AlMMCs, When SiC particles reinforced AlMMCs used for manufacturing automotive brake disc, the wear resistance improved while noise is considerably minimized. Aluminum based composite materials may be used to manufacture brake rotors, brake pistons, brake pads and calipers, other brake system components, automotive drive shafts, rocker arms and other automotive parts. By the application of aluminum and aluminum based composite materials in automotive sector high-performance of products, reduction in weight and increment in energy efficiency can be achieved. AlMMCs usually are used to manufacture engine pistons, connecting rods, automobile brake systems parts, etc. Indirectly by the use of aluminum an improvement in the life span observed where it used like an engine, car frame, along with the gearbox function, breaking mechanism, and other automotive structures. Automotive companies are trying to fulfill the customer demands which includes enhanced internal conveniences and sophisticated electronic systems for safety navigation and entertainment which all carry unnecessary weight otherwise, which become a main reason of shifting to lightweight materials as a solution to these challenges, In addition, a big reason of increasingly turning to MMCs is to satisfy stringent requirements for fuel economy. MMCs provide the power to meet unique and stringent design needs in order to conquer certain obstacles to automotive manufacturers [12].

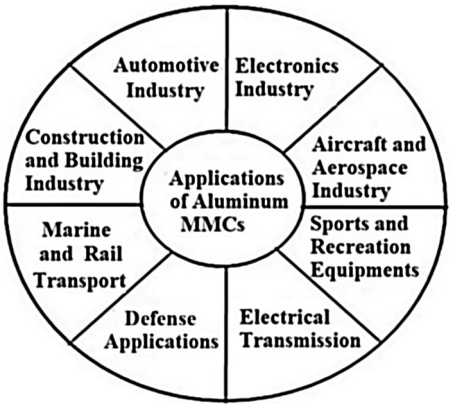


**Fig 4.** Different Applications of Aluminum MMCs.

#### 5.1.1. Piston and connecting rods

Piston works at a very high temperature and pressure in the cylinder so the material which use for both must have high thermal conductivity and high resistance to wear. AlMMCs can be used for this which provide excellent quality at the competitive cost and the reduction in the weight of a piston can also be possible. The use of AlMMCs in the engine block enables engines to achieve operating temperatures quicker and to provide superior wear resistance and decreased weight. In comparison, a MMC casting process is much easier than the conventional piston production system. The use of MMCs for pistons provides large numbers of positive results. Silicon carbide is typically used as reinforcement materials especially for racing vehicles. A satisfactory weight reduction observed in connecting rod when manufactured by the use of AlMMCs, Vibrations during the entire operation were minimized. This also reduces the load on the shaft which leads to reduce the fuel consumption in the engine and engine power is improved [13].

#### 5.1.2. Break and chassis

Automotive disk brakes and brake calipers are an area where substantial weight reduction can be achieved. In order to lower their costs and maximize machinability generally AlMMCs used, ceramic reinforced AlMMCs used in braking disks of high-speed trains and in the racing car braking systems, For the manufacturing of brake disks and pipes Specific casting methods are used. A growing number of car manufactures are now using AlMMCs in production of braking systems. The specific mechanical properties of material used to make the chassis can affect the performance of the vehicle which includes strength and toughness as well as the properties which decides safety of the occupants in serious crashes, For this generally material used which enhance both torsional rigidity and energy absorption for better vehicle dynamics [14,15].

### 5.2. Rail and marine transportation

AlMMCs used in the manufacturing of rail car to reduce the weight. Aluminum is still the excellent material for railroad cars, Due to lightweight, excellent resistance to corrosion. Marine transportation has additionally been changed with the usage of Al alloys and its composites. The usage of these materials has allowed a rise in speed, size, and fuel efficiency of ships as well as boats. The use of aluminum-based materials often allows greater maneuverability and access to low drawn ports. Aluminum based composite materials meet high-speed ship construction, protection and fire hazard control specifications. Aluminum can effectively handle high-speed water transport loads [16].

### 5.3. Aerospace and aircraft applications

The aerospace industry has grown rapidly, the specific properties of materials have been made more and more demanding. AlMMCs have a wide range of aerospace applications. In the space, due to acute environment condition, advanced materials with the good characteristics which includes low thermal expansion coefficient (CTE), high, dimensional stable structures, good specific stiffness and light-weight required. Obviously, within the near-earth orbit, typical phenomena like the vacuum, radiation like thermal, ionizing are naturally found and encountered by spacecraft. Due to The development of aluminum matrix composites the manufacturing of high-performance aircraft and satellites became possible [17].

Aluminum based Composites have certain special advantages so that they can be commonly used in aerospace, airspace and military industry. The pioneer in using MMC in Military aircraft is Lockheed-martin, an American company. Aluminum matrix composites have been extensively used in the manufacturing of aircraft, helicopters and other large aircraft wings, rudders, flaps, fuselage and other components. AlMMCs also used to produce the fan outlet guide vanes, for engines in aircraft, these composites can be used to manufacture aircraft airframe structure, camera lens direction frame, hydraulic pipes, helicopter rotor system, landing gear and valve body. AlMMCs can be used in satellite due to its good conductivity and low thermal expansion coefficient. Al matrix composites are also used in the manufacture of optical and electronic components, as ultra-light Space, Such type applications of these composites indicates its importance and these composites are expected to have a high life expectancy [18].

### 5.4. Construction and building industry

In the building and construction sector AlMMCs widely used. The two key advantages of using aluminum are their strength and lightweight. Over time, aluminum has been tested as an important material because aluminum and also its alloys are certainly recyclable, in modern structures, a big part of the aluminum used is made of recycled product. Advanced AlMMCs can increase the capacity of structure [19].

### 5.5. Electronics and electrical industry

Advanced electronic equipment of the new generation, generates more heat than previous types. Hence, heat dissipation in electrical applications is becoming a major concern. Heat is a major cause of failure of any electronic device, so heat elimination or dissipation from the system to its greatest extent is required for this heat sinks are commonly used in electronic devices and have become almost necessary in computer devices as in processing units. The small flaw in the thermal expansion coefficient between the material and the thermal sink leads to thermal fatigue. The material ideal for electrical and electronic applications, must have thermo-mechanical and thermo-physical properties with maximum heat transfer, combined with minimal thermal distortion. The advancement of metal matrix composites having high thermal conductivity (CT) and low thermal expansion coefficient (CTE) is one of the recent developments in new materials and become the key to solving the rapid heat transfer and heat dissipation issues of electronic devices. Many of the reinforcing materials including nitrides, oxides and carbides have an extremely low CTE, when these are combined with aluminum, It provides a material with a low CTE and a high CT. AlMMCs, especially SiC reinforced AlMMCs, because of the low coefficient of thermal expansion, low density and good thermal conductivity, at present, in electronic applications used for electronic packaging and in heat sinks. Electronic packaging materials must structurally support electronic components, protect against the harmful effect of the atmosphere and dissipate electronic component's excess heat. High rigidity, high CT, very low CTE and very low density are the most important characteristics of such materials. The use of AlMMCs in electronic packages has been growing, particularly in aviation, where high costs can be justified by weight savings. AlMMCs having high electric conductivity, lightweight and resistance towards corrosion which makes Aluminum-based composites as an ideal for transmission power from generating stations to companies and homes [20].

### 5.6. Sports and recreation applications

To make sports equipment, the products made by a mixture of materials which incorporates plastics, ceramics, polymers by different fabrication techniques according to the desired shape and design of equipment. Aluminum metal matrix composites are incredibly uses as materials to make products for sport purpose. In many forms of sport products, the use of MMCs has been applied, the use of AlMMCs for the sport equipment continuously increasing due to low cost and lightweight. The material usually used comprises aluminum matrix which reinforcement with materials like SiC and B4C. Recreational items including those utilized in golf, baseball, skiing and various other conveniences as effectively as very competitive sporting tasks always needs high performance material over cost so AlMMCs are an asset for them [21].

### 5.7. Defense applications

In large amounts of conventional weapons, composite material may be used. Fiber reinforced aluminum composites is one of the most widely used composite in making of weapons because of its good overall performance. AlMMCs begin to use in key parts of missiles previously made by beryllium. The advantages of MMCs include lower costs and avoid problems of toxicity related with beryllium. The important elements that are produced by MMCs are the fins of a directed gun due to their strong rigidity. This helps to increase accuracy of a weapon [22].

## 6. Conclusion

Modern technologies offer a broad variety of solutions and guidelines for selection of materials to the manufacturer of products according to different applications, with the current technological developments, the different materials are required with various properties to manufacture product according to the requirement. Obviously, the rapid growth of the technology in industries is combined with the need to use lightweight materials that fulfill industrial and environmental criteria with advantageous mechanical and tribological characteristics. Gradual advancement in manufacturing technologies of materials make possibilities of creation of lightweight MMCs for different applications at lower costs with higher quality. Aluminum and its alloys are one of the most desirable materials with characteristics that can give most of the current requirements and often exhibit reasonable tribological, mechanical features when used as matrix materials in AlMMCs and SiC and Al2O3 are the material generally for reinforcement. AlMMCs gain widespread acceptance in many industrial applications due to their excellent properties, so a study regarding the addition effect of various reinforcements like graphite, fly ash, SiC, etc., in the different proportion to the aluminum matrix is important. The major applications of aluminum based composites are in transportation vehicles, aerospace industry, defense weapons, and electronics and optical instruments. In the field of aluminum-based composite materials, Throughout the world, the application and research mainly focused on particle

reinforced aluminum matrix composite materials but in recent years also on continuous reinforced AlMMCs, and has made great achievements. AlMMCs need continuous research and expecting a good futuristic growth. A good future can be predicted for these composite classes, as the industries have focused on obtaining low-cost, high-performance MMCs.

## Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

## CrediT authorship contribution statement

**Arun Kumar Sharma:** Conceptualization, Investigation, Resources, Writing - original draft, Writing - review & editing, Visualization. **Rakesh Bhandari:** Conceptualization, Investigation, Resources, Writing - review & editing, Visualization. **Amit Aherwar:** Conceptualization, Investigation, Resources, Writing - review & editing, Visualization. **Rūta Rimašauskienė:** Conceptualization, Investigation, Resources, Writing - review & editing, Visualization. **Camelia Pinca-Bretotean:** Conceptualization, Investigation, Resources, Writing - review & editing, Visualization.

## Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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