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MAKE IN INDIA

Cast Metal Matrix Composites Over Last 50 Years and Future Opportunities in India

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Abstract

Research in Cast Metal Matrix Composites in India was started in 1968 at IIT Kanpur and now India is considered as one of the world leaders in Cast MMC Research according to a recent Business Report. Metal matrix composites (MMCs) have received increased attention worldwide due to their potential applications in aerospace, automobile, railways, motorcycles, computer hardware and recreational equipment and the total volume of MMC industry is now 400 million per year. This paper reviews the progress in Cast MMCs over 50 years in India in relation to the developments worldwide and discusses future of next generation cast metal matrix composites. The information on MMC industry worldwide including major producers and users of cast MMCs will be presented. Some cast MMCs discussed will include Aluminium-Graphite, Aluminium-Silicon Carbide, Aluminium-Alumina and Aluminium-Fly Ash. Current and future directions in Cast MMCs, including manufacture of foundry produced Nano-Composites, functionally gradient materials, syntactic foams; self-healing and self-lubricating composites will be presented. Solidification issues in casting metal matrix composites, the major challenges in casting metal matrix composites will be outlined. Recent progress in manufacture of lightweight Self-lubricating cylinder liners for compressors, piston and rotary engines in Al-Graphite and Al-Graphite-SiC composites are discussed. The opportunities of manufacturing cast metal matrix composite in foundries in India for internal consumption and exports will be presented.

Keywords: Metal matrix composites, hybrid composites, functionally graded materials, stir casting, nanocomposites, self-healing and self-lubricating composites, lightweight

Introduction

The increased demand for lightweight materials with high specific strength, stiffness and better tribological properties in the automotive, aerospace and defence sectors have accelerated the development and use of MMCs[1-4]. Automotive manufacturers strive to reduce vehicle weight in order to improve performance, lower fuel consumption and reduce emissions. Many automotive components made of steel and cast iron could be replaced by components made from less dense metals or metal matrix composites. In recent years, aluminium metal matrix composites (MMCs) used for tribological components have attracted more and more interests. They are widely used as high-speed rotating or reciprocating mass items such as pistons, connecting rods, drive shafts, brake rotors and cylinder liners. Aluminium and its alloys are widely used for the fabrication of MMC because they are light in weight, economically viable, amenable for production by various processing techniques and possess high specific strength and good corrosion resistance properties. India has had a leadership in research on cast MMCs over the last 50 years and there is a very large opportunity for manufacturing these composites in Indian foundries for internal consumption and exports. There is an exponential growth in paper publication on cast metal matrix composites from Indian Institutions like IITs, NITs, IISc, DMRL, and CSIR.

Aluminium matrix composites have been developed to meet very high-performance defence and aerospace needs[1-7]. As material cost became a more significant consideration, the emphasis shifted toward particulate-reinforced materials, with the goal of a lower cost, high volume product that could be used in automotive and commercial aerospace applications. Many of the major aluminium companies had MMC development programmes in the 1980's and early 1990's. Alcan, through its Duralcan subsidiary, established a 25 million pound per year production capability for particulate-reinforced aluminium composites.

The conventional cast MMC developed and used contains mainly one type of discontinuous reinforcement[6-7]. However, in order to introduce the multifunctional property requirement, more than one type of reinforcements are introduced within a single component leading to hybrid MMC with enhanced and synergistic properties. Similarly, in recent times, newer functionally graded/ gradient MMC with selective and graded reinforcement are processed to obtain location specific properties within a component. Nano MMC is synthesised with large enhancement in mechanical and physical properties, with minimum reinforcement addition. In recent years, metal matrix composites have been extended to produce self-healing, self-cleaning and self-lubricating castings.

Processing of cast metal matrix composites

The evolution of different metal matrix composite systems has led to the development of newer processing techniques, in addition to conventional metal processing techniques. The major criteria for the selection of a process rely on the type of composite system to be fabricated, the properties required and the component to be produced. Apart from the adoption of conventional foundry processing methods for making MMC, newer solidification and casting process were developed suiting to the shape and property requirements of engineering components. The processing methods of MMC are widely classified into primary and secondary processes. The primary processing techniques combining matrix and reinforcements to produce the basic composite systems are classified into liquid and solid state processes. The important primary liquid state processes are stir casting or vortex method, infiltration, in-situ and spray deposition processes. The important solid state processes are powder metallurgy and diffusion bonding. The developments in liquid state processing methods used in foundries for making cast MMC are described here. Stir casting or vortex method is the simplest and economical process available for the manufacture of MMC in large quantities in foundries. In this process, the molten metal is stirred and dispersoids are added through the vortex[5]. Figure 1 shows the schematic diagram of liquid metal stir casting process. Surface treatments and addition of wetting promoters into the melt can enhance the particle distribution and its bonding in the matrix. This method is commonly used for fabricating discontinuous dispersoids reinforced MMC. The hybridisation can be carried out by either melting a composite and introducing the second reinforcement or introducing both the dispersoids in the matrix alloy simultaneously.

Infiltration process involves infiltrating the liquid metal through the interspaces in a porous preform made out of reinforcements, with or without the application of an external force. The infiltration of liquid metal could be made with or without the application of an external force. Figure 2 shows the schematic diagram of squeeze infiltration process. Synthesis of porous ceramic/fibre preforms with sufficient strength to withstand the squeeze pressure is a crucial step in processing. The infiltration processes are classified depending on the nature and type of force applied as pressure, pressureless, vacuum, combination of pressure and vacuum, etc. Infiltration process is very effective for synthesising fibre-fibre, fibre-particle, functionally gradient and selectively reinforced hybrid composite systems, with high volume percentages of reinforcements[5]. Similarly, hybrid composites with high volume fraction of reinforcements could also be successfully fabricated. In-situ composites are lower in cost as it involves synthesis of reinforcements within the melt itself using chemical reactions or pyrolysis of polymers[5].

In-situ process involves generating the

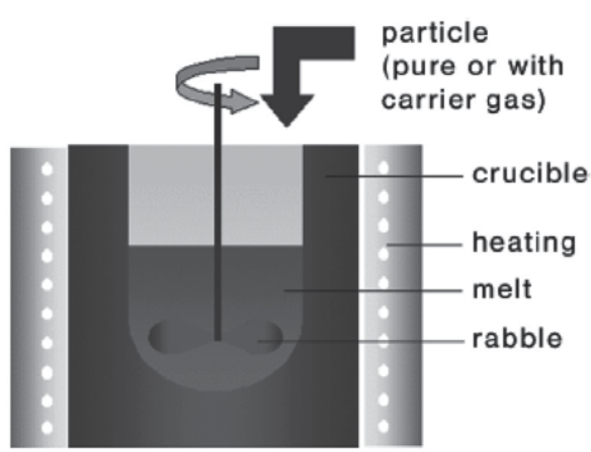

Fig 1: Schematic diagram of liquid metal stir casting process

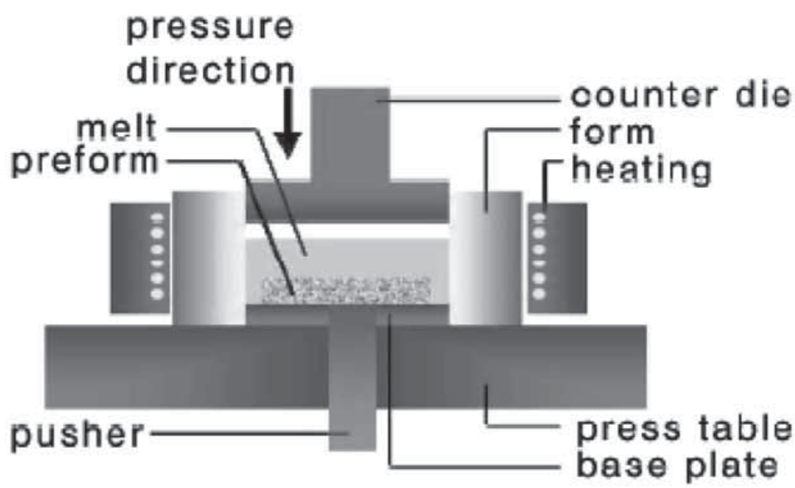

Fig 2: schematic diagram of squeeze cast infiltration process

reinforcement material by chemical reactions from the matrix alloy within the melt with the introduction of selective additives and the composites thus produced are known as in-situ composites. In-situ hybridisation of reinforcements could be made by the reaction between the various components of the system to produce two or more dispersoids, which contribute to the properties of the composites. In situ hybridisation can also be made by the reaction between the surface coatings of reinforcement with the matrix to produce a second type dispersoids. The advantage of in-situ method is the development of composites dispersoids both in micro and nanosize range and stable metal-reinforcement interface.

Hybrid metal matrix composites

Hybrid metal matrix composites (HMMC) are the second generation composites, wherein more than one type, shape or size of reinforcements are used to obtain the synergistic properties of the reinforcements and the matrix. Al-SiC-Graphite Composites are one of the potential hybrid systems for automotive application with lighter weight, better wear resistance and antifriction behaviour. Cast Al-SiC-Graphite Composites have been developed for cylinder liner applications[6]. The addition of graphite to aluminium-SiC provides three unique benefits viz greater stability of particle distribution during casting process, improved machinability and increased resistance to wear. Graphite provides seizure resistance while the hard particulate provides abrasion resistance, resulting in a material with excellent dry sliding wear performance.

In order to produce a lighter engine compared to cast iron liners, an aluminium block and a hypereutectic aluminium silicon alloy has been developed as an alternative to cast-iron blocks and liners. To replace the cast iron liners, a new engine block has been developed in which the cylinder liners of aluminium based composite reinforced with short hybrid fibres of alumina and carbon are used. The self-lubricating effect of carbon fibre contributes to improvements in antiseizure when there is no continuous oil film in the cylinder bore surfaces. The engine blocks and the cylinder liners developed using Al-1.5Cu-9.6Si (ADC12)-12% Al_2O_3(sf)-9%C(sf). HMMC are light in weight and have lower wear than conventional engine block. These engine blocks can be efficiently mass produced through preform production and casting process and possess better wear resistance due to Al_2O_3, improved lubrication by carbon fibre, 50% the weight of cast iron and improved cooling efficiency. MMC engine blocks manufactured using Saffil - carbon fiber hybrid preforms reinforced with aluminium have been used by Honda in the Accord, Ascot, Innova (two-wheeler) and the S2000 models.

Functionally graded metal matrix composites (FGMMC)

Functionally Gradient / Graded Materials (FGM) are emerging as a new class of materials, exhibit gradual transitions in the microstructure and/or the composition in a specific direction, the presence of which leads to variation in the functional performance within a part. The presence of gradual transitions in material composition in FGM can reduce or eliminate the deleterious stress concentrations and result in a wide gradation of physical and / or chemical properties within the material. FGMs are in their early stages of evolution and expected to have a strong impact on the design and development of new components and structures with better performance.

A wide variety of processing methods are available for the fabrication of functionally graded metal-ceramic composites, hence it is difficult to group them. Mortensen and Suresh have classified the processing methods of FGM broadly as constructive and transport-based processes[7-9]. In the constructive processes, the FGM or the precursors such as preforms are constructed layer by layer with appropriate gradients in the distribution of constituent phases. On the other hand, the transport based processes create the gradients in local microstructure and/or composition in a component by the natural transport phenomena such as the flow of fluid, the diffusion of atomic species or by heat conduction. In liquid state processes, the matrix is either fully or partially molten during the formation of FGMMC. The important liquid state processing methods are infiltration, gravity aided settling, centrifugal casting, sequential casting and spray forming. Among the various fabrication techniques mentioned above, important solidification processing methods are infiltration, settling, centrifugal casting, spray casting and laser melt processing, which are described below.

Infiltration process involves the preparation of graded ceramic preform containing graded porosity and its infiltration with the liquid metal with or without the application of pressure or vacuum. Al FGMMC for automotive applications has been successfully fabricated, featuring graded transition from aluminium to ceramic reinforced aluminium at surfaces. One of the critical steps involved in this process is the fabrication of the preform with the required concentration of the particles. In the case of higher volume fraction, preform should not experience excessive deformation during pressure assisted infiltration of metal. Figure 3 shows the aluminium-SiC composite prepared using a graded porous SiC preform and by squeeze infiltration technique. Aluminium pistons locally reinforced along their crown surface have been produced using preforms containing four layers of distinct volume fraction of 21, 25, 40 and 51% of hybrid reinforcements of alumina short fibres and aluminium titanate particles, which are created by conventional slurry and binder methods[8]. These graded composites have shown superior thermal crack resisting performance, compared with corresponding unreinforced and ungraded MMC pistons.

Metal matrix nano composites

Nanostructured and ultrafine grained materials offer exotic ranges of physical, chemical, electronic and engineering properties over the conventional bulk microstructured materials. The greatest challenges in the development of nano and ultra-fine grained MMC for wider applications are the cost and complexity in processing these MMC as well as the cost of nano- scale reinforcements. The improvement in properties of nano and ultra-fine grained MMC greatly depends on size, distribution, volume fraction and properties of the reinforcements and the interfacial behaviour between matrix and reinforcements. The high surface area of nano size reinforcements tends to agglomerate and generates problem in uniform distribution in the matrix when processed through conventional methods. Nano MMCs are processed by liquid metal dispersion of nanosize reinforcements, infiltration of liquid into a nano-dispersoids preform and rapid solidification techniques.

Liquid Metal Dispersion involves production of nano or ultrafine grained MMC by dispersing the fine reinforcements into the molten metallic matrices by some form of agitation. Liquid metal stir casting, ultrasonic dispersion and electromagnetic dispersion are some of the variants of liquid metal dispersion processes. Aluminium Alloy-Al_2O_3 nano MMC have been fabricated by combination of stir mixing and ultrasonic mixing processes with the addition of wetting agent to the molten alloy[10].

Cast metal matrix syntactic foams

Syntactic foams are made in foundries by pressure infiltration and stir casting process[11-13]. Hollow ceramic particulates including fly ash cenospheres are infiltrated by aluminum alloy, to create aluminium fly ash syntactic foam as shown in Fig 4. The density of this Cast Aluminium Hollow cenospheres foam is 1.4 gm/cc and demonstrates the potential of reducing the weight of aluminium by the incorporation of fly ash cenospheres. This opens up the possibility of producing syntactic foams with other cenospheres, not just fly ash, in foundries. These foam materials have high damping capacity and energy absorbing characteristics of interest to automotive industries. In addition to fly ash other hollow micro balloons of alumina have also been incorporated in the matrix of metal to synthesize syntactic foams.

Applications

Metal matrix composites have emerged as one of the advanced engineering materials having potential application in the areas of aerospace, automotive, defence,

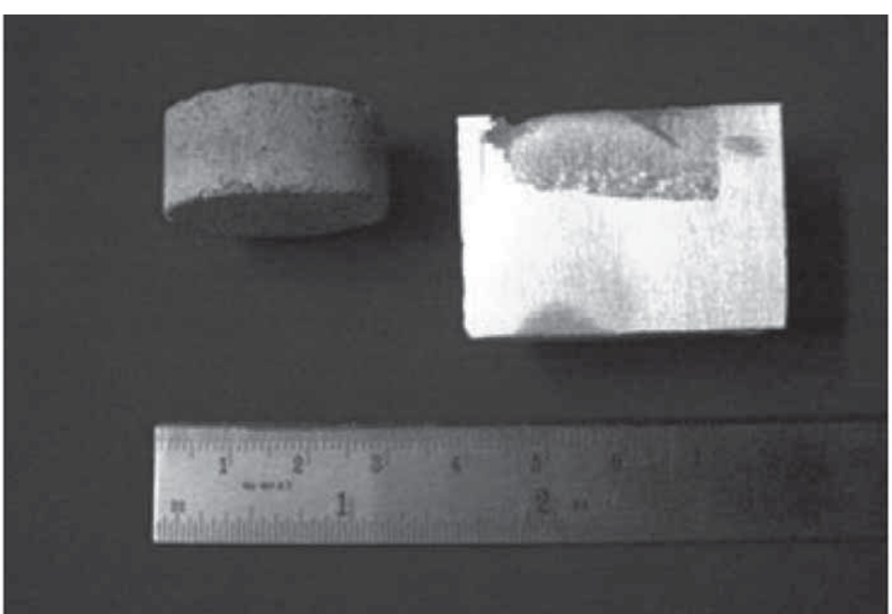

Fig 3: Graded SiC perform and aluminium–SiC infiltrated specimen

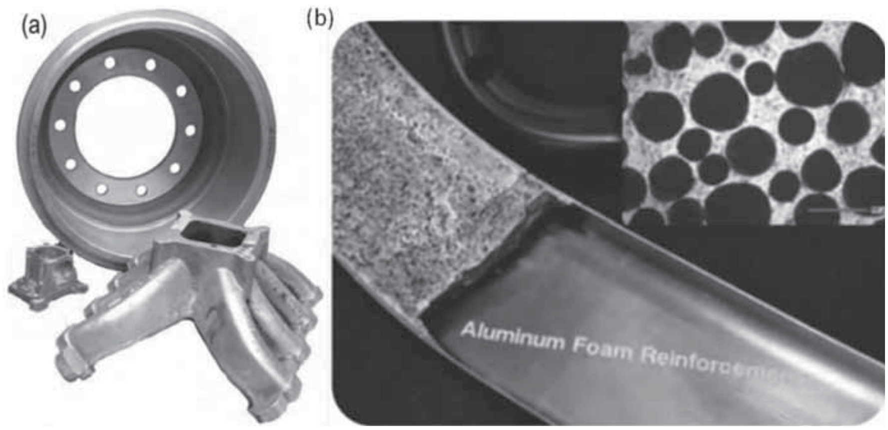

Fig 4: (a) Automotive components made of aluminium- and magnesium-fly ash composites developed at UWM[11] (b) Aluminium-fly ash cenosphere syntactic foam (micrographinset) within a steel frame. (Courtesy of Bob Purgert)

electronics, general engineering and other advanced structures[14-15]. They can be tailored to have the required superior properties such as high specific strength and stiffness, increased wear resistance, enhanced high temperature performance, and improved thermal conductivity, low coefficient of thermal expansion, high damping capacity and better thermal and mechanical fatigue and creep resistances than those of monolithic material. This has led to their widespread use in automotive, aerospace, thermal management and heat sink, and recreational equipment applications.

Several automotive components including pistons, cylinder liners, brake rotors and connecting rods have been made out of aluminium composites as shown in Fig 5. Table-1 shows the development of metal matrix composites by different industries [Metal-Matrix Composites in Industry: A Database of Companies, Materials, and Products 2011]. Continuous fibre reinforced aluminium was used in the Space Shuttle and Hubble Space Telescope. The metal matrix composites used for aerospace components are shown in Fig 6 and brake rotors for trains made out of Al-SiC composites in foundries are shown in Fig 7.

Since Lead is being banned in a number of copper alloys for bearing and plumbing applications, lead-free copper-graphite composites have been developed at UWM USA as a substitute for lead containing copper alloys for plumbing and bearing applications. Graphite particles have been shown to impart machinability and lubricity similar to lead at much lower costs without the associated toxicity. Graphite is also much cheaper and abundantly available compared to Bismuth and Selenium which are being proposed as alternatives to lead. Figure 8 shows a large number of plumbing fixtures

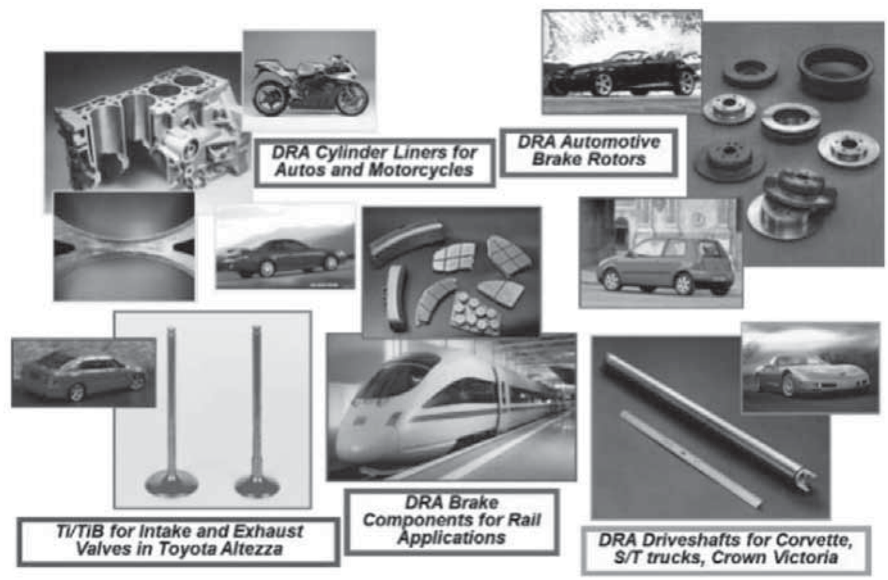

Fig 5: MMC uses in automotive applications as cylinder liners, brake rotors, intake and exhaust valves, and driveshaft etc

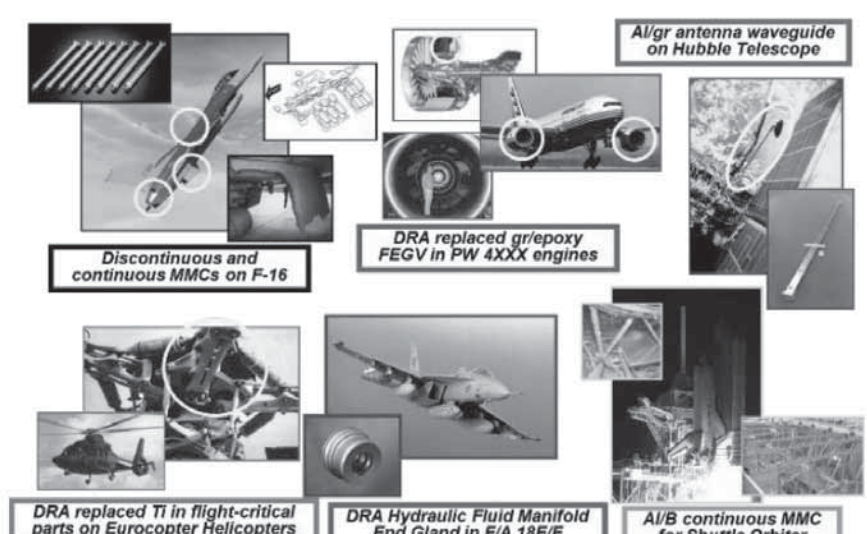

Fig 6: MMC uses in space industries

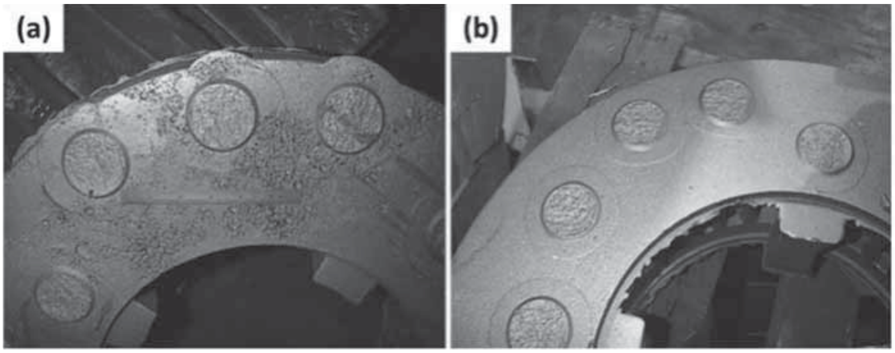

Fig 7: Train rotor made from Duralcan

and bearings cast in lead-free copper-graphite alloys at UWM. By centrifugally cast copper alloy-graphite composite, one can concentrate the graphite particles on the inner periphery, where they selectively reinforce and provide solid lubrication for bearing applications. Instead of using lead, one can in a single step, produce selectively reinforced, self-lubricating copper graphite alloy, by centrifugal casting of copper alloy-graphite melts for bearings[16-18].

For more than a decade, Kolben Schmidt, Mahle, AE and Toyota have pioneered the use of Saffil fibre reinforced pistons for diesel engines, while Honda Motor Company focused on the reinforcement of engine blocks. Cast aluminium matrix composite brake drums and rotors have been used for the Prowler and EV-1, driveshaft for the Corvette and GM S/T truck, and tire studs in Scandinavia. In 1990, Honda launched a new generation of aluminium engine blocks with fibre reinforced cylinder walls replacing traditional cast iron liners. The first model selected for production was the Prelude Si, a 16-valve in-line 4-cylinder engine, using a new casting process to incorporate the Saffil-carbon fibre hybrid preforms discussed earlier. Elimination of the cast iron liner using MMC technology allows a reduction in material thickness between the adjacent bores. Tightening the cylinder spacing in this way results in reduction in the overall length of the engine and a weight saving on the block of around 4.5 kg. Honda has since expanded the use of MMC engine blocks in their vehicles like Accord, Ascot, Innova and the S2000 models. Honda has also developed a high pressure die casting (HPDC) process for manufacturing the MMC engine blocks which reduces process costs and enables widely available equipment to be employed. Hence, discontinuously reinforced MMCs based on particulates, short fibres and whiskers have become the potential composite systems for automotive sector. The potential components, which can be fabricated using metal matrix composites by Centrifugal Casting, are given in Table-2. Table-3 summarises the use of metal matrix composites in automotive applications developed at UWM[5]. Table-4 shows the major companies producing discontinuously reinforced cast MMC and their engineering components[5].

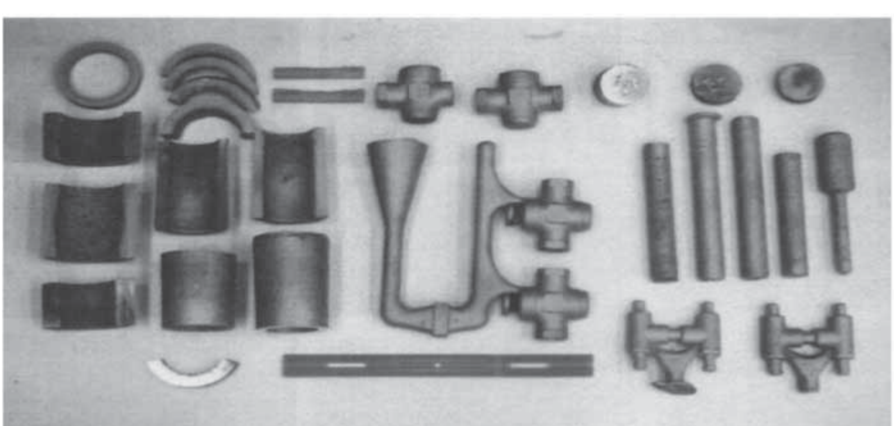

Fig 8: Montage of lead-free copper-graphite composite castings

Al-SiC (Aluminium Silicon Carbide), a metal-matrix composite, provide highly reliable and cost-effective thermal management solutions for electronic packaging. It offers high thermal conductivity (~200 W/mK) and a tailored, low Coefficient of Thermal Expansion (CTE). The low density and high strength and stiffness values give AlSiC added advantages over more dense, traditional materials in applications where weight savings or shock and vibration tolerance are required. Several SiCp/Al and Grp/Al (Fig 9) electronic packages have been space-qualified and are now flown on communication satellites and Global Positioning System satellites. These components are not only significantly lighter than those produced from previous metal alloys, but they provide significant cost savings through net-shape manufacturing.

NIIST CSIR Trivandrum in India has developed functionally graded aluminium matrix composite prototype components fabricated by centrifugal casting for engineering application at National Institute for Interdisciplinary Science and Technology, Trivandrum. Various prototype FGM components such as (a) cylinder liners and gears (b) brake rotor disc and (c) piston had been fabricated by centrifugal casting technique (Fig 10(a-c)). Al-SiC FGM fishing boat cable pulleys are reported to be fabricated successfully by centrifugal casting method[19]. They have also developed prototype of light

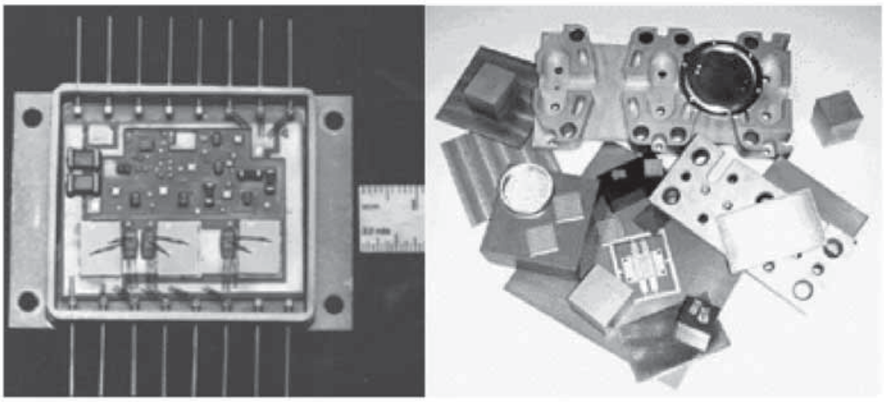

Fig 9: Discontinuously reinforced aluminium MMCs for electronic packaging applications: (a-left) SiCp/Al electronic package for a remote power controller (photo courtesy of Lockheed Martin Corporation), and (b-right) cast Grp/Al components (photo courtesy of MMCC, Inc.)

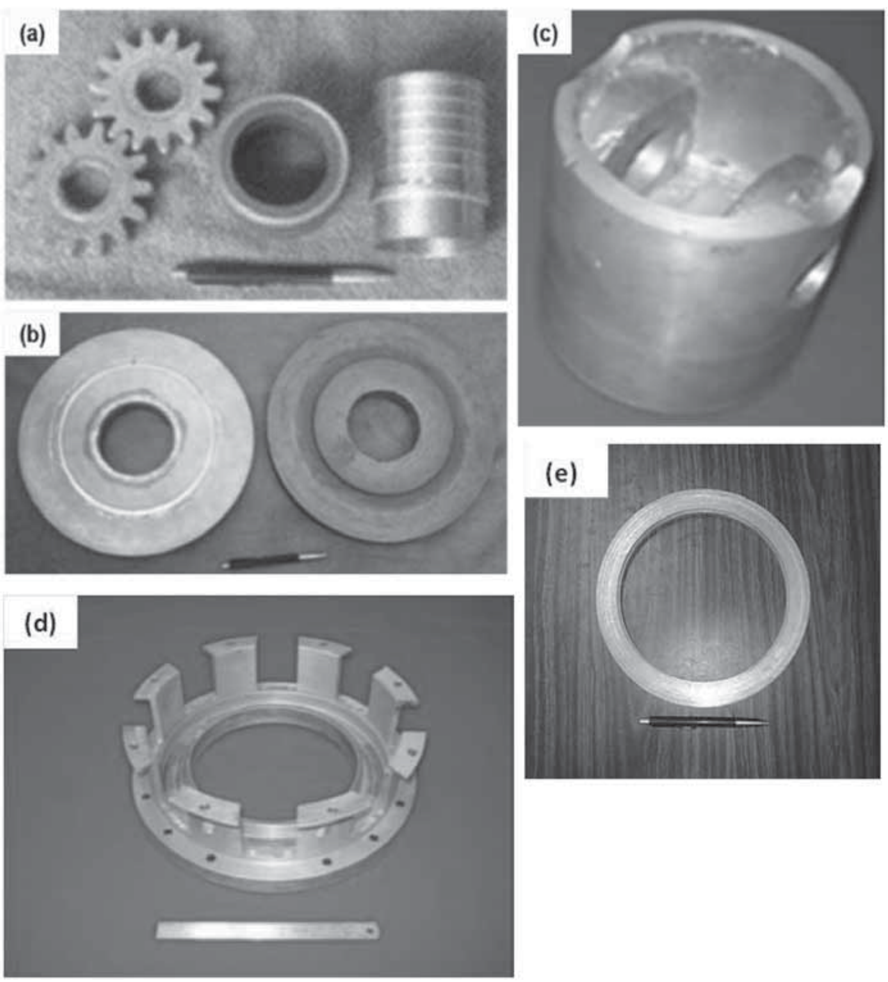

Fig 10: Functionally graded aluminium matrix composite prototype components at CSIR-NIIST(a) cylinder liners and gears (b) brake rotor disc (c) piston for engineering application (d) Al (356)-15%SiC metal matrix composite first gear housing and (e) piston ring processed by liquid metal stir casting and shaped by sand casting [19]

weight Al (356)-15% SiC metal matrix composite first gear housing and piston ring for application in engines of battle tanks (Fig 10(d-e)). These components possess enhanced wear resistance and heat dissipation behaviour coupled with light weight. Fabrication of functionally graded components by centrifugal casting method has wide scope for different engineering applications.

Major use of Al-SiCp composite has been for the brake rotor and heat sink applications. Composite brake rotors are as effective as cast-iron rotors in braking applications, in addition to the weight savings which is around 50~60% of the weight of cast iron. Toyota has also used A359/20 vol% SiCp composite brake rotors in their electric vehicle (the RAV4-EV) (Fig 11). Lotus Elise was also released with Al-SiCp composite brake rotors.

Intelligent Composites has developed hybrid Al-SiC Graphite cylinders for internal combustion and rotary engines (Fig 12) and compressors.

Advanced Materials Processing Research Institute (AMPRI) CSIR at Bhopal has developed high strength aluminium matrix composites with greater formability through liquid metallurgy route for automobile and structural applications[20]. Pressure die cast Al-SiC composite brake drums have been produced with 66% weight reduction in comparison to cast iron brake drum (Fig 13(a-b)). Al-SiC composite Torpedo's nose cone was developed for defence applications which exhibited around 40 to 50% higher damping capacity and noise attenuations shown in Fig13c. 35 million cars are running in India. Even 10% of its requirement being met with cast composites could lead to market in excess of Rs1000 crore. Prototype components such as forged connecting rod, light weight high performance helicopter blade sleeve have also been developed at AMPRI Bhopal.

Next generation self-lubricating, self-cleaning and self-healing metal matrix composites

The technology to manufacture cast Metal Matrix Composites is being extended to smart composites including

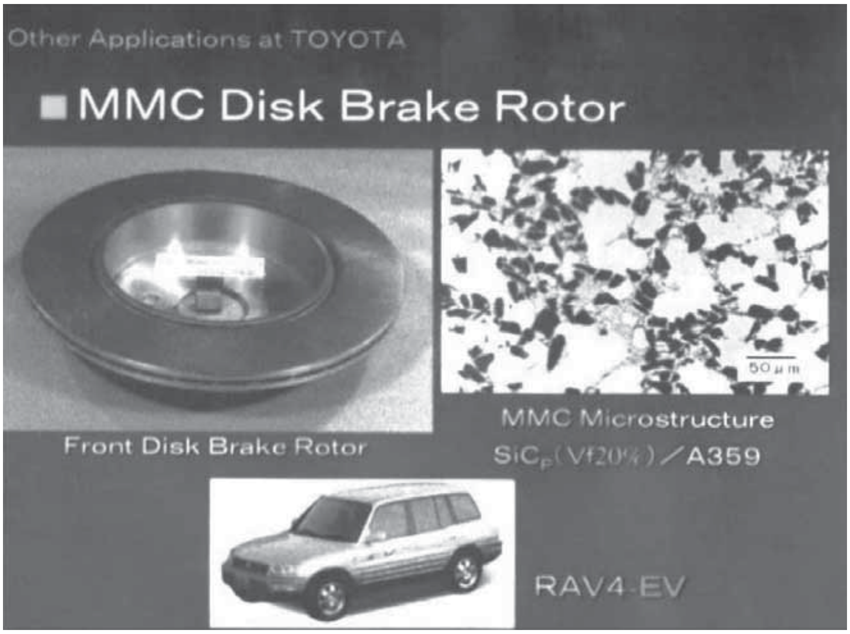

Fig 11: A359/20 vol% SiCp composite brake rotor for electric vehicle

Fig 12: Al-SiC Graphite piston cylinder made by Intelligent Composites including hybrid Al-SiC-Gr

Table-1: Aluminium MMC Components developed and used in automobiles

Composite System	Production Method	Automotive Component	Manufacturer
Al-Graphite(p)	Gravity casting	Cylinder liners	AEC, Ferrari, Hiromotors and Alfa Romeo
Al -$SiC_{(p)}$	Gravity Casting	Piston	Lanxide, Dural
Al-$SiC_{(w)}$	Squeeze Casting	Connecting Rod	Nissan
Al-SiC_P	Compocasting Squeeze Casting Extrusion	Shock Absorber Cylinder	Mitsubishi
Al-$SiC_{(W)}$	Squeeze Casting	Diesel Engine Piston	Niigata
Al-$SiC_{(p)}$	Squeeze Casting Extrusion	Drive Shaft	Dural, GKN
Al-Alumina, $C_{(f)}$	Low Pressure Forming	Cylinder liner	Honda
Al-$Alumina_{(p)}$	Gravity Casting	Brake Rotor	Dural
Al-$Alumina_{(f)}$	Squeeze Casting	Piston Crown	Toyota
Al-Alumina $_{(f)}$	Squeeze Casting	Piston Ring Grove	Toyota
Al-$SUS_{(CF)}$	Squeeze Casting	Con Rod for Petrol Engine	Honda
Al -$FP_{(CF)}$	Squeeze Casting	Connecting Rod	Du-pont
Al-$Al_2O_{3(sf)}$ -$C_{(sf)}$	Squeeze Casting	Engine	Honda

self-lubricating, self-cleaning, and self-healing and shape-restoring composite materials. Incorporation of solid lubricants like graphite and mica in the matrices of metals like aluminium reduces friction coefficient and wear rate, and

Table-2: Components which can be manufactured by Centrifugal Casting

Bearings, bearing bushings and cages	Heat exchanger tubes	Railroad car wheels and bearings
Brackets	Hoist drums	Retorts
Brake drum liners	Hollow extrusion billets	Rocket and missile fins
Cylinder liners	Hydraulic and pneumatic cylinder tubes	Sewage pipe
Dental prosthetics	Impellers and blades	Shells for canned motor pumps
Ductile iron pressure pipe	Paper and textile mill rolls and drums	Sleeves
Electric motor rotors	Piston rings and piston inserts	Stator shells for atomic power
Electronic module cases and covers	Pressure vessels	Steel mill rolls
Gas turbine rings	Pulleys and sheaves	Submarine masts
Gears, gear blanks, including bi-metallic	Pump rotors and liners	Thin-wall aerospace components

Table-3: Use of Metal Matrix Composites in Automotive Applications Developed at UWM [5].

METAL-MATRIX COMPOSITE (MMC) MATERIALS BEING DEVELOPED AT UNIVERSITY OF WISCONSIN–MILWAUKEE FOR USE IN AUTOMOTIVE APPLICATIONS

Property	Materials	Application
Wear resistance	SiC-, Al_2O_3-, and/or 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 microballoon-reinforced syntactic foam MMCs	Crumple zones, frame members and reinforcements, pedestrian impact zones, batteries
Self-cleaning	MMCs with hydrophobic reinforcements, biomimetic coatings, and surface finishes	Water pumps, water jackets, exposed metallic components
Self-lubricating	Micro and nano MMCs incorporating graphite, MoS_2, TiB_2, 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_2O_3 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	Intake manifolds, accessory brackets, low-load brackets, oil pans, valve covers, alternator covers, water pumps

Table-4: Selected companies who have produced and used discontinuously reinforced cast MMC components[5]

3M Company, Specialty Fibers and Composites, USA	Ford Motor Company, USA
Advanced Refractory Technologies, Inc., USA	Foster-Miller Inc, USA
Alcan, USA	General Motors, USA
Alcoa, USA	Gibbs Die Casting Corporation, USA
Ametek, Inc, USA	High Performance Materials Group (HPMG), USA)
Bell Helicopter Textron, Inc, USA	Hitchiner Manufacturing Company, Inc, USA
Boeing, USA (www.boeing.com)	Honda Motor Company, Ltd,
Chesapeake Composites Corporation, USA	KolbenschmidtPierburg AG, Germany (www.kolbenschmidt.de)
Composite Metal Technologies Plc, UK	London & Scandinavian Metallurgical Co Ltd (LSM), UK
Cycotech Pty Ltd, Australia)	M-Cubed Technologies, Inc, USA (www.mmmt.com)
Cymat Corporation, Canada	Mahle GmbH, Germany (www.mahle.com)
DaimlerChrysler AG, Germany	Mazda Motor Corporation, Japan
Delphi Automotive Systems, USA	Metal Matrix Cast Composites (MMCC), USA
Dynamet Technology, Inc, USA	(MC-21), USA (http://www.mc21inc.com)
Motorola, Inc, USA (www.motorola.com)	Porsche, Germany (www.porsche.com)
PCC Advanced Forming Technology, USA (www.pcc-aft.com)	Siemens AG, Germany (www.siemens.com)
Sandvik AB	Toyota Motor Corporation, Japan (http://www.toyota.com/)
GKN Sinter Metals Engineering GmbH.	Hitachi Metals, Ltd.
Plansee SE	CPS Technologies Corporation, USA
Sumitomo Electric Industries Ltd.	Deutsche Edelstahlwerke GmbH
3A Composites	Santier
Materion Corporation, USA	Ceradyne, Inc.
Metal Matrix Cast Composites LLC	TISICS Ltd.
Daewha Alloytic Co. Ltd.	Thermal Transfer Composites LLC
ADMA Products, Inc.	Inco Ltd, USA

provide ability of components to run in boundry lubrication, suggesting the possibility of oil-less engines. In recent years hydrophobic reinforcements have been incorporated in metals which are hydrophilic, to impart hydrophobicity and self-cleaning capabilities to metals and enhance their corrosion resistance property. Cast Metal Matrix Composites have been synthesised which have capabilities of self-healing cracks, similar to biological materials like bone and skin which self-heal after being damaged. Self-healing metal matrix composites have been synthesised by incorporating shape memory alloys in the matrix of solders, aluminium, magnesium and zinc; selected cracks in the matrix are closed when the shape memory alloy shrinks remembering its original shape; if the temperature of healing is high for some liquid to form on crack surfaces, the crack is welded. Alternately hollow micro balloons or micro tubes containing a low melting healing liquid within it, are incorporated in the matrix of metals to form a composite; selected cracks fracture the micro balloons and upon heating the low melting healing agent within micro balloons or micro tubes can melt and flow into the crack sealing the crack[21-26].

Research imperatives

- To date, fibres or particles have been incorporated mainly in conventional monolithic alloy matrices commonly used by foundries, and it has not been able to get the best advantage of Cast Metal Matrix Composites.
- There is a need to develop special reinforcements including surface treated reinforcements for cast MMCs.
- There is a need to develop techniques for rapid infiltration of preforms, including techniques for rapid pressure-less infiltration.
- Need of using reinforcements that are much smaller, nanometer instead for micron size and disperse them

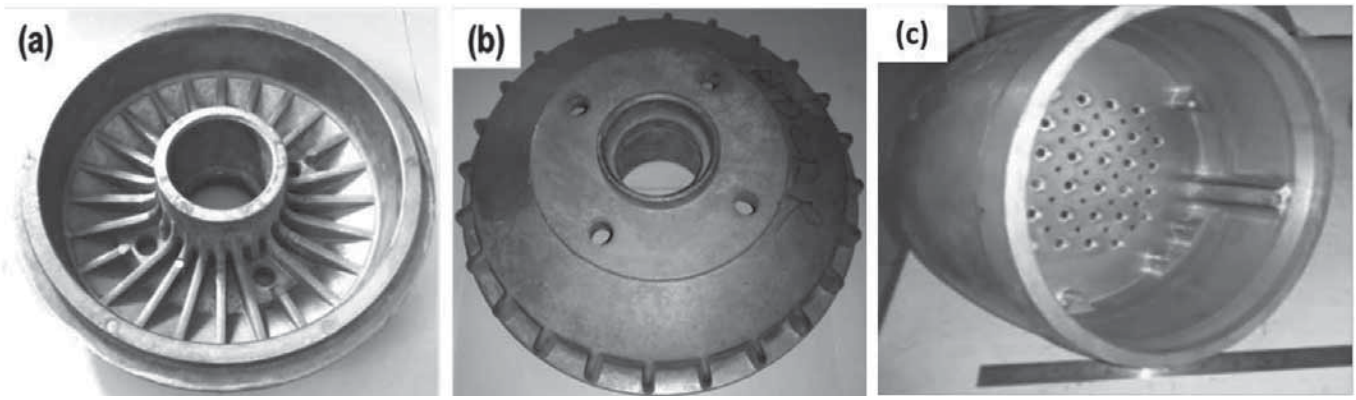

Fig 13: Pressure die cast Al-SiC composite brake drums (a) inner (b) outer view, 66% weight reduction in comparison to cast iron brake drum and (c) LM13-10wt% SiCp Composite Nose cone with higher damping capacity and higher strength[20]

in the matrix uniformly with good interface bonding. These particles act like artificial precipitates and impart high strength that makes the metal composites more desirable.

- There is a need to produce machinable composite that allows parts to be more affordable.
- Need to develop pathways to recycle cast metal matrix components at the end of life.
- There is a need to develop low cost filled castings with low embodied energy reinforcements.

Conclusions

The potential of next generation metal matrix composites as an advanced material for the automotive, aerospace and electronic engineering applications has been demonstrated by the development of various composite systems and their components. The replacement of high density conventional materials based on ferrous alloys by Al MMC has been observed. The light weight, high specific strength and modulus, better high temperature performance and wear and antifriction behaviour are the attractive characteristics. However, the cost of production has to be reduced by development of suitable mass production techniques for near-net shape components with consistent properties. Squeeze casting technique has established its importance for the fabrication of Al MMC for automotive applications. Hybrid and functionally graded Al matrix composites are some of the recent developments and have demonstrated their potential as futuristic materials.

There is a great potential for manufacture and use of next generation metal matrix composite castings in India in view of strong research base in India and very large markets within India and for export abroad. Foundry produced metal matrix composites will have large market for scooters, cars (both IC Engine and electric cars), trucks, trains and motorcycles in India especially in view of high price of petroleum-based fuels and lubricants and increasing pollution levels in several cities). Several million cars are produced in India each year and even if 10% of these cars having 30 kg of metal matrix composites is used in each car, it would lead to very large markets in India, significant amount of energy can be saved and emission reduced through the use of metal matrix composites for brake rotors, cylinder liners, pistons, plumbing fixtures, and other components in transport systems including railways, cars, trucks, motorcycles, scooters, and aerospace components. In addition, there are significant opportunities to manufacture heat sinks made out of cast metal matrix composites in computer hardware and space applications.

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