International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 07 Issue: 06 | June 2020 www.irjet.net p-ISSN: 2395-0072

Applications of Metal Matrix Composites in Modern Engineering

Prof A. N. Purant[1], Prof. R. R. Joshi [2], Prof. S. B. Mhetre[3], Prof. A. A. Patil[4]

[1]*Prof A. N. Purant, DKTE's Textile and Engineering Institute, Ichalkaranji*
[2]*Prof. R. R. Joshi, DKTE's Textile and Engineering Institute, Ichalkaranji*
[3]*Prof. S. B. Mhetre, DKTE's Textile and Engineering Institute, Ichalkaranji*
[4]*Prof. A. A. Patil, DKTE's Textile and Engineering Institute, Ichalkaranji*

Abstract - *MMCs are made by dispersing a reinforcing material into a metal matrix. The reinforcement surface can be coated to prevent a chemical reaction with the matrix. For example, carbon fibers are commonly used in aluminium matrix to synthesize composites showing low density and high strength. However, carbon reacts with aluminium to generate a brittle and water-soluble compound Al4C3 on the surface of the fiber. To prevent this reaction, the carbon fibers are coated with nickel or titanium boride.*

Metal matrix composites (MMC s) usually consist of a low-density metal, such a s aluminum or magnesium, reinforced with particulate or fibers of a ceramic material, such as silicon carbide or graphite. Compared to unreinforced metals, MMCs offer higher specific strength and stiffness, higher operating temperature, and greater wear resistance, as well as the opportunity to tailor these properties for a particular application.

However, MMC s also have some disadvantages compared with metals. Chief among these are the higher cost of fabrication for high-performance MMC s, and lower ductility and toughness. Presently, MMC s tends to cluster around two extreme types. One consists of very high performance composites reinforced with expensive continuous fibers and requiring expensive processing methods. The other consists of relatively low-cost and low-performance composites reinforced with relatively inexpensive particulate or fibers. The cost of the first type is too high for any but military or space applications, whereas the cost/benefit advantages of the second type over unrein- forced metal alloys remain in doubt.

Key Words: Metal Matrix Composite,

1. INTRODUCTION

Current markets for MMC s are primarily in military and aerospace applications. Experimental MMC components have been developed for use in aircraft, satellites, jet engines, missiles, and the National Aeronautics and Space Administration (NA S A) space shuttle. The first production application of a particulate-reinforced MMC in the United States is a set of covers for a missile guidance system.

The most important commercial application to date is the MMC diesel engine piston ma d e by Toyota. This composite piston offers better wear resistance and high-temperature strength than the cast iron piston it replaced . It is estimated that 300,000 such pistons are produced and sold in Japan annually. This development is very important because it demonstrates that MMC s are a t least not prohibitively expensive for a very cost sensitive application. Other commercial applications include cutting tools and circuit-breaker contacts.

This document is template. We ask that authors follow some simple guidelines. In essence, we ask you to make your paper look exactly like this document. The easiest way to do this is simply to download the template, and replace(copy-paste) the content with your own material. Number the reference items consecutively in square brackets (e.g. [1]). However the authors name can be used along with the reference number in the running text. The order of reference in the running text should match with the list of references at the end of the paper.

Metal matrix composites with high specific stiff ness and strength could be used in applications in which saving weight is an important factor. Included in this category are robots, high-speed machinery, and high-speed rotating shafts for ships or /and vehicles. Good wear resistance, along with high specific strength, also favors MMC use in automotive engine and brake parts. Tailorable coefficient of thermal expansion and thermal conductivity make them good candidates for lasers, precision machinery, and electronic packaging. However, the current level of development effort appears to be inadequate to bring about commercialization of any of these in the next 5 years, with the possible exception of diesel engine pistons.

Based on information now in the public domain, the following military applications for MMC s appear attractive: high-temperature fighter aircraft engines and structures; high-temperature missile structures; and spacecraft structures. Testing of a National Aerospace Plane (NA SP) prototype is scheduled for the early to mid 1990s, which might be too early to include MMC s. How- ever, it ma y be possible to incorporate MMC s in the structure or engines of the production vehicle.

1.1 Reinforcement

The reinforcement material is embedded into a matrix. The reinforcement does not always serve a purely structural task (reinforcing the compound), but is also used to change physical properties such as wear resistance, friction coefficient, or thermal conductivity. The reinforcement can be either continuous or discontinuous. Discontinuous MMCs can be isotropic and can be worked with standard metalworking techniques, such as extrusion, forging, or rolling. In addition, they may be machined using conventional techniques, but commonly would need the use of polycrystalline diamond tooling (PCD).

Continuous reinforcement uses monofilament wires or fibers such as carbon fiber or silicon carbide. Because the fibers are embedded into the matrix in a certain direction, the result is an anisotropic structure in which the alignment of the material affects its strength. One of the first MMCs used boron filament as reinforcement. Discontinuous reinforcement uses "whiskers", short fibers, or particles. The most common reinforcing materials in this category are alumina and silicon carbide.[1]

2. MANUFACTURING AND FORMING METHODS

MMC manufacturing can be broken into three types—solid, liquid, and vapor.

2.1 Solid state methods

Powder blending and consolidation (powder metallurgy): Powdered metal and discontinuous reinforcement are mixed and then bonded through a process of compaction, degassing, and thermo-mechanical treatment (possibly via hot isostatic pressing (HIP) or extrusion)

Foil diffusion bonding: Layers of metal foil are sandwiched with long fibers, and then pressed through to form a matrix

2.2 Liquid state methods

Electroplating and electroforming: A solution containing metal ions loaded with reinforcing particles is co-deposited forming a composite material

Stir casting: Discontinuous reinforcement is stirred into molten metal, which is allowed to solidify

Pressure infiltration: Molten metal is infiltrated into the reinforcement through use a kind of pressure such as gas pressure

Squeeze casting: Molten metal is injected into a form with fibers pre-placed inside it

Spray deposition: Molten metal is sprayed onto a continuous fiber substrate

Reactive processing: A chemical reaction occurs, with one of the reactants forming the matrix and the other the reinforcement

2.3 Semi-solid state methods

Semi-solid powder processing: Powder mixture is heated up to semi-solid state and pressure is applied to form the composites.[2][3][4]

2.4 Vapor deposition

Physical vapor deposition: The fiber is passed through a thick cloud of vaporized metal, coating it.

2.5 In-situ fabrication technique

Controlled unidirectional solidification of a eutectic alloy can result in a two-phase microstructure with one of the phases, present in lamellar or fiber form, distributed in the matrix.[5]

3. RESIDUAL STRESS

MMCs are fabricated at elevated temperatures, which is an essential condition for diffusion bonding of the fiber/matrix interface. Later on, when they are cooled down to the ambient temperature, residual stresses (RS) are generated in the composite due to the mismatch between the coefficients of the metal matrix and fiber. The manufacturing RS significantly influence the mechanical behavior of the MMCs in all loading conditions. In some cases, thermal RS are high enough to initiate plastic deformation within the matrix during the manufacturing process.[6]

4. APPLICATIONS

- High performance tungsten carbide cutting tools are made from a tough cobalt matrix cementing the hard tungsten carbide particles; lower performance tools can use other metals such as bronze as the matrix.
- Some tank armors may be made from metal matrix composites, probably steel reinforced with boron nitride, which is a good reinforcement for steel because it is very stiff and it does not dissolve in molten steel.
- Some automotive disc brakes use MMCs. Early Lotus Elise models used aluminum MMC rotors, but they have less than optimal heat properties, and Lotus has since switched back to cast iron. Modern high-performance sport cars, such as those built by Porsche, use rotors made of carbon fiber within a silicon carbide matrix because of its high specific heat and thermal conductivity. 3M developed a preformed aluminum matrix insert for strengthening cast aluminum disc brake calipers,[7] reducing weight by half compared to cast iron while retaining similar stiffness. 3M has also used alumina preforms for AMC pushrods.[8]
- Ford offers a Metal Matrix Composite (MMC) driveshaft upgrade. The MMC driveshaft is made of an aluminum matrix reinforced with boron carbide, allowing the critical speed of the driveshaft to be raised by reducing inertia. The MMC driveshaft has become a common modification for racers, allowing the top speed to be increased far beyond the safe operating speeds of a standard aluminum driveshaft.

VW – Lupo (Tdi) – Rear Brake Drums
Material : MMC – A359/SiC/20p
Weight of Drum : 1.55 kg
Material costs: < 5 US dollar /kg

- Honda has used aluminum metal matrix composite cylinder liners in some of their engines, including the B21A1, H22A and H23A, F20C and F22C, and the C32B used in the NSX.
- Toyota has since used metal matrix composites in the Yamaha-designed 2ZZ-GE engine which is used in the later Lotus Lotus Elise S2 versions as well as Toyota car models, including the eponymous Toyota Matrix. Porsche also uses MMCs to reinforce the engine's cylinder sleeves in the Boxster and 911.
- The F-16 Fighting Falcon uses monofilament silicon carbide fibers in a titanium matrix for a structural component of the jet's landing gear.
- Specialized Bicycles has used aluminum MMC compounds for its top of the range bicycle frames for several years. Griffen Bicycles also made boron carbide-aluminum MMC bike frames, and Univega briefly did so as well.
- Some equipment in particle accelerators such as Radio Frequency Quadrupoles (RFQs) or electron targets use copper MMC compounds such as Glidcop to retain the material properties of copper at high temperatures and radiation levels.[9][10]
- Copper-silver alloy matrix containing 55% by volume diamond particles, known as Dymalloy, is used as a substrate for high-power, high-density multi-chip modules in electronics for its very high thermal conductivity.

Space Shuttle main cargo bay struts
Material: MMC – 6061/B/50f
Total weight saving : 145 kg (-44% v/s Aluminium)
Material costs: > 1000 US Dollar / kg

- Aluminium-Graphite composites are used in power electronic modules because of their high thermal conductivity, the adjustable coefficient of thermal expansion and the low density.

5. CONCLUSIONS

MMCs are nearly always more expensive than the more conventional materials they are replacing. As a result, they are found where improved properties and performance can justify the added cost. Today these applications are found most often in aircraft components, space systems and high-end or "boutique" sports equipment. The scope of applications will certainly increase as manufacturing costs are reduced.

In comparison with conventional polymer matrix composites, MMCs are resistant to fire, can operate in wider range of temperatures, do not absorb moisture, have better electrical and thermal conductivity, are resistant to radiation damage, and do not display outgassing. On the other hand, MMCs tend to be more expensive, the fiber-reinforced materials may be difficult to fabricate, and the available experience in use is limited.

REFERENCES

[1] Materials science and Engineering, an introduction. William D. Callister Jr, 7th Ed, Wiley and sons publishing
[2] Wu, Yufeng; Gap; Kim, Yong (2011). "Carbon nanotube reinforced aluminum composite fabricated by semi-solid powder processing". Journal of Materials Processing Technology. 211 (8): 1341–1347. doi:10.1016/j.jmatprotec.2011.03.007.
[3] Wu, Yufeng; Yong Kim, Gap; et al. (2010). "Fabrication of Al6061 composite with high SiC particle loading by semi-solid powder processing". Acta Materialia. 58 (13): 4398–4405. doi:10.1016/j.jmatprotec.2011.03.007.
[4] Wu, Yufeng; Yong Kim, Gap; et al. (2015). "Compaction behavior of Al6061 and SiC binary powder mixture in the mushy state". Journal of Materials Processing Technology. 216: 484–491. doi:10.1016/j.jmatprotec.2014.10.003.
[5] University of Virginia's Directed Vapor Deposition (DVD) technology
[6] Aghdam, M. M.; Morsali, S. R. (2014-01-01). Residual Stresses in Composite Materials. Woodhead Publishing. pp. 233–255. ISBN 9780857092700.
[7] Aluminium matrix composite (AMC) inserts for reinforced brake calipers (Archived)
[8] Industry Solutions - Metal Matrix Composites - High performance, high strength, metal matrix composite material (Archived)
[9] Ratti, A.; R. Gough; M. Hoff; R. Keller; K. Kennedy; R MacGill; J. Staples (1999). "The SNS RFQ Prototype Module" (PDF). Particle Accelerator Conference, 1999. 2 (1): 884–886. doi:10.1109/PAC.1999.795388. ISBN 978-0-7803-5573-6. Archived from the original (PDF) on 2010-03-26. Retrieved 2009-03-09.
[10] Mochizuki, T.; Y. Sakurai; D. Shu; T. M. Kuzay; H. Kitamura (1998). "Design of Compact Absorbers for High-Heat-Load X-ray Undulator Beamlines at SPring-8" (PDF). Journal of Synchrotron Radiation. 5 (4): 1199–1201. doi:10.1107/S0909049598000387. PMID 16687820.