Materials and Technologies Developed at UWM

I. Self Lubricating Materials

The automotive industry requires lightweight metal matrix materials with improved friction and wear resistance to achieve significant weight reductions and improve fuel efficiency of vehicles. Cylinder liners, pistons, bearing surfaces (including wind energy equipment and compressors), cam shaft tappets, lifters, rockers, brake components and plumbing features) are examples of the use of new low cost and lightweight self lubricating composites developed at UWM. These composites contain solid lubricants like graphite dispersed in metals like Aluminum, Magnesium and Copper to reduce frictional energy loss. In addition these composites can run under boundary lubrication in the event of loss of lubricant. These composites can be manufactured at low costs in conventional Foundries.

II. Ultra light Materials

At UWM Composite Center, materials can be tailored to be lightweight and at the same time have better properties, such as high specific strength and specific stiffness, high hardness and wear resistance, low coefficient of friction and thermal expansion or high thermal conductivity. Frame members and reinforcements, cylinder liners, water passages, catalytic converters, batteries and wind turbine blades are examples of the applications of these materials. These materials include metal matrix micro and nanocomposites, and syntactic foams, and can help to reduce the weight of transportation equipment, stationary machinery and structures. These ultra light materials can be made at low costs in conventional foundries.

III. Self Healing Materials

These are materials that incorporate 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, connecting rods, aerospace components and wind turbine blades are examples of the application of these materials. These materials can heal a crack after it has opened by either closing or filling the crack. These self healing materials can be made at low costs in conventional foundries.

IV. Energy Absorption Materials

These are ultra light materials that are designed to protect people from the impact of weapons, vehicles or explosions, by the absorption of the energy generated during these impacts. Crumple zone, frame members and reinforcements, helmets, military vehicles, blast resistant structures, wind turbine blades, and pedestrian impact zones are examples of the application of these technologies. They consist of metals in which hollow microbaloons of ceramics or other metals are incorporated to form metal matrix syntactic foams. Certain Magnesium syntactic foams can have densities less than water and can float in water. These syntactic foams can be made at low costs in conventional foundries.

V. Self Cleaning Metallic Components for Water Industry

These are surface treatments for metallic components which impart super hydrophobicity, self cleaning, antifouling, deicing and corrosion resistance to alloys, including brasses, irons, aluminum alloys and Hastelloy used in water industry and will be of interest to other industries including food processing and aircraft industry.

Technologies Developed at UWM

1. Self Lubricating Cast Aluminum Graphite particle components for pistons, liners, bearings, compressors, and scrolls.

2. Cast Aluminum-Fly Ash components for transportation and electromechanical machinery, including intake manifolds, mounting brackets, meter casings, and transmission housing.

3. Metal Matrix, Micro, and Nanocomposites castings for structural and wear resistant applications, in transportation, electro mechanical machinery, recreation equipment, and heat management industry.

4. Cast Aluminum-Graphite fiber composite components for structural and thermal management applications.

5. Lead free Copper Graphite components for bearing and plumbing applications, including water taps, water meters, valves, comp lings, pipes, and tanks.

6. Cast Iron Base Composites with enhanced modulus and decreased density for transportation and machinery applications.

7. Lead Fly Ash Cenosphere Composites for lightweight battery applications and lighter weight X ray shields.

8. Metal Matrix – hollow ceramic syntactic foams for energy absorbing applications.

9. Polymer Fly Ash Cenosphere composites for low cost, lightweight structural, and energy absorbing applications.

10. Polymer Natural Fiber Composites for structural and nonstructural applications.

11. Self-Healing alloys and composites.

12. Self-cleaning components and surfaces.

List of New Metal Matrix Composites Developed at UWM Composites Center

- Al-Graphite, Al-Al2O3
- Al-Graphite Fiber
- Al-SiC Particle
- Al-Alumina Particle
- Al-Zircon (ZrSiO4)
- Al-Titania (TiO2)
- Al-Zirconia (Zr02)
- Al-Illite Clay
- Al-Fly Ash
- Al-SiO2
- Iron-Al2O3
- Iron-Titanium Carbide
- Lead-Graphite
- Lead-Fly Ash
- Al-Graphite-Silicon Carbide
- Al-Graphite-Alumina
- Al-Alumina (47nm)
- Copper-Graphite Particle
- Copper-Fly Ash
- Zinc-Graphite
- Zinc-Fly Ash
- Zinc-Alumina
- Magnesium-Graphite
- Magnesium-Fly Ash
- Al 3D Carbon Fiber Weave

List of Industrial Uses of Metal Matrix Composites Inspired by Research

- Aluminum Conductor Composite Core (ACCC)
- Lower Drag Brace for F16-Ti-SiC
- Lightweight Composite core for Power Lines (CTC) Al-composite core
- Brake rotors for German high speed train ICE-2 Al-Si, Mg and SiC
- Cylinder liner – LOKASIL-composite used in Porsche Boxter
- Space Shuttle Orbiter Main Cargo Bay Struts
- Hubble Space Telescope Antenna Waveguide Mast – 6061/C melt infiltration P-100 carbon fibers
- Spartan Auxiliary Mounting Plate
- Hubble Space Telescope Antenna Waveguide Mast-6061/C melt infiltration P-100 carbon fibers
- Spartan Auxiliary Mounting Plate
- F-16 Fuel Access Door Covers – 6092/SiC/17.5p
- F-16 Ventral Fins – 6092/SiC/17.5p rolled P/M
- Fan Exit Guide Vanes – 6092/SiC/17.5 rolled P/M
- Euro copter Blade Sleeves – 2009/SiC/15p-T4 P/M to replace Ti-6Al-4VV-22 Hydraulic Manifold – A206/SiC/40p pressure infiltration (cheaper than whisker-reinforced)
- Ti-MMC Exhaust Valves/Toyota Altezza : Ti-SiC
- MMC Cylinder Liners / Honda Prelude Al-SiC-C
- MMC Brake Rotors or Brake Drums Al-SiC
- MMC Driveshaft / Chevy Corvette
- In Situ MMC / ISPRAM –Extruded Seat Fastening Rail of Airbus
- Forged Connecting Rod Al-SiC
- Recreational products – golf, bicycles, athletic shoes Al-SiC
- DRA Brake Fin for Walt Disney World Big Thunder Railway Thrill Ride Al-SiC
- Generator Housing – Al and Mg reinforced with hybrid-composite-6092/SiC/17.5p DRA
- MMC electronic cooling plate – Toyota Hybrid Al-SiC
- Al-SiC Microwave packaging used in LEO communication satellites
- Al/Bf tubular struts in frame and rib truss for mid fuselage for spacecraft.

Applications of Metal Matrix Composites in Different Sectors

COMPONENT		SYSTEM
SPACE	Antenna Waveguide Mast Microwave Thermal Packaging Power Semiconductor Base	Hubble Space Telescope Commercial LEO satellites Commercial GEO comsats
AUTOMOTIVE	Drive shaft Exhaust Valves Engine Block Cylinder Liner Brake Rotor	Chevy Corvette, Pickup Toyota Altezza (Asian Market) Honda Prelude Plymouth Prowler
AERO-PROPULSION	Fan Exit Guide Vane	Pratt & Whitney 4XXX engines
AERO-STRUCTURES	Ventral Fin Fuel Access Door Covers Rotor Blade Sleeve	F – 16 F – 16 Eurocopter EC-120, N-4
THERMAL MANAGEMENT	Power Semiconductor	Motorola Power Chip
RECREATION	Bicycle Frame Brake Fins	Specialized Stump-Jumper Disney Thunder Mountain Thrill Ride

U.S. Patents, Granted and Filed

1. "Process for Producing at Least one Constituent Dispersed in a Metal," U.S. Patent 3,600,163, filed Oct. 7, 1966 (cited in 22 later patents), granted to F. A. Badia and Pradeep K. Rohatgi, August 17, 1971.

2. "Method of Making Synthetic Resin Composites with Magnetic Fillers," U.S. Patent 3,867,299, filed 8-11-71, cited in 15 later patents, granted to Pradeep K. Rohatgi, February 18, 1975.

3. "Mold Modifications for Eliminating Freckle Defects in Roll Castings," U.S. Patent 3,882,942, filed 05-24-73, granted to Pradeep K. Rohatgi and L. R. Woodyatt on May 13, 1975.

4. "Composite Metal Bodies," U.S. Patent No. 3,885,959 filed May 10, 1971, granted to F. A. Badia and Pradeep K. Rohatgi on May 27, 1975.

5. "Method for Separating and Recovering Kish Graphite from Mixtures of Kish Graphite and Fume," U.S. Patent 4643349 granted to P. K. Rohatgi, Jan 13, 1976.

6. "Process for the Manufacture of Aluminum-Graphite Composite for Automobile and Engineering Applications," U.S. Patent No. 4,946,647 filed May 4, 1988, granted to Pradeep K. Rohatgi, et al. on August 7, 1990.

7. "Copper Graphite Composite," U.S. Patent 5,200,003 filed 12/28/90, granted to Pradeep K. Rohatgi on April 6, 1993.

8. "Synthesis of Metal Matrix Composites Containing Fly Ash, Graphite, Glass, Ceramics or other Metals," U.S. Patent No. 5,228,494 filed May 1, 1992, granted to Pradeep K. Rohatgi, July 20, 1993.

9. "Thermal Management of Fibers and Particles in Composites," U.S. Patent 5,407,495, granted to Pradeep K. Rohatgi on April 18, 1995.

10. "Nonferrous Cast Metal Matrix Composite," U.S. Patent No. 5,803,153 filed on May 19, 1994, and granted to Pradeep K. Rohatgi on August 8,1998.

11. "Process for Casting a Light Weight Iron Based Material," U.S. Patent No. 5,765,624 granted to R. Hathaway and Pradeep K. Rohatgi on June 16, 1998.

12. "Methods of Producing Metal Matrix Composites Containing Fly Ash," U.S. Patent No. 5,711,362 filed on November 29, 1995, granted to Pradeep K. Rohatgi, Jan 27, 1998.

13. “Cast Aluminum Metal Matrix Composites,” U.S. Patent No. 6,183,877 B-1 filed on August 20, 1997 and granted to J. E. Bell, P. K. Rohatgi, T. F. Stephenson and A.E.M. Warner on February 6, 2001.

14. “Metal Fly Ash Composites and Low Pressure Infiltration Methods for Making the Same,” U.S. Patent No. 5,899,256 filed October 3, 1997 and granted to Pradeep K. Rohatgi on May 4, 1999. (Also Patented in EPO, France, Germany, Italy, Spain, U.K.)

15. “Metal Matrix Composite Including Homogeneously Distributed Fly Ash, Binder and Metal,” U.S. Patent No. 5,897,943 filed January 3, 1997 and granted to Pradeep K. Rohatgi on April 27, 1999.

16. “Method of Making an Aluminum Base Metal Matrix Composite,” U.S. Patent No. 5,626,692 application filed on March 1, 1994 and granted on May 6, 1997 to P. K. Rohatgi, J. E. Bell and T. Stephenson.

17. “Separation of Cenospheres from Flyash,” U.S. Patent 8074804B-2 granted Dec 13, 2011 to B. Ramme, J. Noegel, and P. Rohatgi.

18. “Self Healing Structural Alloys - Including Aluminum and Self-Healing Solders,” U.S. Patent Application no. 12/537,675 filed on August 7, 2009 by Pradeep K. Rohatgi.

Indian Patents

19. "Preparation of Metal Graphite, Mainly Copper-Graphite Composite by Casting Method," Indian Patent No. 124304 granted to Pradeep K. Rohatgi, A. K. Khare, and P. K. Kelkar, 1972.

20. "Preparation of Aluminum-Alumina Composite," Indian Patent 124305A granted to P. K. Rohatgi, S. Ray, and P. K. Kelkar, 1972.

21. “Aluminum-base metal matrix composite,” granted to Pradeep K. Rohatgi, 186823 381/Del/93 April 16, 1993.

22. “A method to produce a metal matrix composite containing reinforcing material,” 189673 366/Del/94, granted to Pradeep K. Rohatgi, March 30, 1994.

23. “A process for making casted nonferrous metal matrix composite shapes,” 190612, 1367/Del/94, granted to Pradeep K. Rohatgi, October 28, 1994.

24. “A process for making metal matrix composites,” Indian Patent No. 0582/DEL/92, granted to P.K.Rohatgi on February 12, 2000.

25. “Synthesis of Metal Matrix Composites”, Indian Patent No. 582/Del/92 (Sl. No. 185174) granted to P.K. Rohatgi on November 23, 2000.

26. “An aluminum-base matrix composition and a method for the preparation thereof,” Indian Patent No. 381/DEL/93, granted to P.K.Rohatgi on November 17, 2001.

27. “A process for making nonferrous metal matrix composite shapes,” Indian patent No. 1367/DEL/94 granted to P.K.Rohatgi on September 8, 2003.

European, Australian and Canadian Patents

28. "Aluminum Base Alloy-Particulate Graphite Composites," Australian Patent 58,777,685 granted to Pradeep K. Rohatgi, et al. on October 3, 1988.

29. "Manufacturing Aluminum Alloy-Graphite Composite," British Patent GB 2194799 granted to P. K. Rohatgi et al. on March 14, 1990.

30. "Aluminum Base Metal Matrix Composite," European Patent 567284 granted to Pradeep K. Rohatgi, on November 10, 1993.

31. "Aluminum Base Metal Matrix Composite", Canadian Patent No. 2,094,369, granted to P.K. Rohatgi, J.A. Bell and T.F. Stephenson on April 19, 2001.

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Metal Matrix Composites Offer Automotive Industry Opportunity to Reduce Vehicle Weight, Improve Performance

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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].

Advanced metal-matrix composites

The Center for Composite Materials and the Center for Advanced Materials Manufacture (CAMM) at the University of Wisconsin-Milwaukee (UMW) are leading forces behind several innovations in the field of advanced cast metallic materials. Metal-matrix composites are metals or alloys that incorporate particles, whiskers, fibers, or hollow microballoons made of a different material, and offer unique opportunities to tailor materials to specific design needs. These materials can be tailored to be lightweight and with various other properties including:

- High specific strength and specific stiffness
- High hardness and wear resistance
- Low coefficients of friction and thermal expansion
- High thermal conductivity
- High energy absorption and a damping capacity

In addition to these properties, new MMCs are being developed at UWM with self-healing, self-cleaning, and self-lubricating properties, which can be used to enhance energy efficiency and reliability of automotive systems and components.

Pistons and cylinder liners

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[5]. 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[6]. The graphite-containing aluminum has a lower friction coefficient 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[6,7]. 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 graphite shears under wear conditions it creates a continuous film of graphite on the aluminum and reduces the wear rate of the liner. The measured friction coefficient of Al-graphite composites is as low as 0.2[6]. Application of this material for cylinder liners in lightweight aluminum-engine blocks enable engines to reach operating temperatures more quickly while providing superior wear resistance, improved cold start emissions, and reduced weight[8]. Aluminum-based composite liners can be cast in place using conventional casting techniques, including sand, permanent mold, die casting, and centrifugal casting.

METAL-MATRIX COMPOSITE (MMC) MATERIALS BEING DEVELOPED AT UNIVERSITY OF WISCONSIN-MILWAUKEE FOR USE IN AUTOMOTIVE APPLICATIONS		
Properties	**MATERIALS**	**APPLICATIONS**
Wear Resistant	Micro and Nano MMC's reinforced with Silicon Carbide (SiC), Alumina (Al_2O_3) and/or Graphite	Bearing surfaces, cylinder liners, pistons, cam shafts, tappets, lifters, rockers, brake components
Lightweight/ Energy Absorption	Syntactic foam MMC's incorporating fly ash cenosphere and other low density ceramic microballoons	Crumple zones, frame members, frame reinforcements, pedestrian impact zones, batteries
Self-Cleaning	MMC's containing hydrophobic reinforcements, biomimetic coatings and surface finishes	Water pumps, water jackets, exposed metallic components
Self-Lubricating	Micro and Nano MMC's incorporating Graphite, Molybdenum Disulfide (MoS_2), Titanium Diboride (TiB_2), Hexagonal Boron Nitride (hBN) or other solid lubricants	Bearing journals, cylinder liners, pistons, cv joints, gear surfaces
Self-Healing	MMC's incorporating shape memory alloys or hollow reinforcements filled with low melting healing agents	Difficult to access, fatigue prone, or critical components, such as driveshafts, wheels, steering knuckles, steering columns, connecting rods
High Conductivity (Thermal)	Micro and Nano MMC's 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 MMC's reinforced with SiC or Al_2O_3 particles, Carbon Nano-Tubes (CNT), Carbon or Nextel fibers, or In-Situ Ceramics	Connecting rods, brake calipers, brake rotors, brake calipers
Low Cost	MMC's containing fly ash or waste sand as fillers	Intake manifolds, accessory brackets, low load brackets, oil pans, valve covers, alternator covers, water pumps

Main bearings

Copper-lead bearings used in crankshaft main-bearing caps can be replaced with lead-free aluminum- or copper-matrix composites containing graphite particles developed at UWM[6,9]. Graphite is nontoxic, and the use of aluminum- and copper-graphite composite bearings as a replacement for leaded copper reduces weight. The bearings also improve wear characteristics because deformation of the graphite particles results in the formation of a continuous graphite film, which provides self-lubrication of the component, allowing for improved component longevity. These materials could benefit virtually all journal bearings in the power train. Selectively reinforced functionally gradient bearings of aluminum-graphite and copper-graphite alloys can be manufactured in a single step by centrifugal casting of metal-graphite suspensions (Figs. 1 and 2).

Fig. 1 — Aluminum-graphite particle composite piston and cylinder liner developed at UWM Center for Composite Materials. The inset microstructure shows that graphite particles concentrate in the inner periphery of the liner.

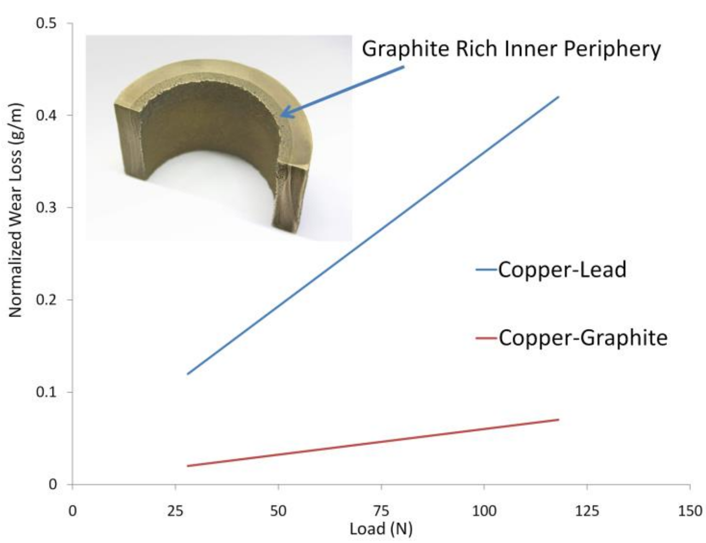

Fig. 2 — Copper-graphite composites outperform leaded copper in normalized wear loss in sliding wear. Inset shows a cross section of an unfinished centrifugally cast copper-graphite bearing.

Connecting rods

With the advent of nanostructured materials, new materials have been developed with exceptional properties exceeding those expected for monolithic alloys or composites containing micron-scale reinforcements. For example, carbon nanotubes have ultrahigh strength and modulus; when included in a matrix, they could impart significant property improvements to the resulting nano-composite.

In another example[10], incorporating only 10 vol% of 50-nm alumina (Al_2O_3) particles to an aluminum alloy matrix using the powder metallurgy process increased yield strength to 515 MPa. This is 15 times stronger than the base alloy, six times stronger than the base alloy containing 46 vol% of 29-μm Al_2O_3, and over 1.5 times stronger than AISI 304 stainless steel. Research is in progress at UWM to cast aluminum-base nano-composites with possible strengths on the order of 0.5 to 1 GPa. However, some processing problems need to be resolved, and challenges of scaling up the technology need to be overcome. For components requiring high strength, such as connecting rods, cast aluminum-matrix nano-composites may be ideal to produce near-net-shape components to replace steel, forged aluminum and titanium components, while reducing reciprocating mass. Figure 3 shows typical microstructure of cast aluminum alloy 206 reinforced with 47-nm alumina particles synthesized at UWM, and the equipment used to synthesize the composite[11].

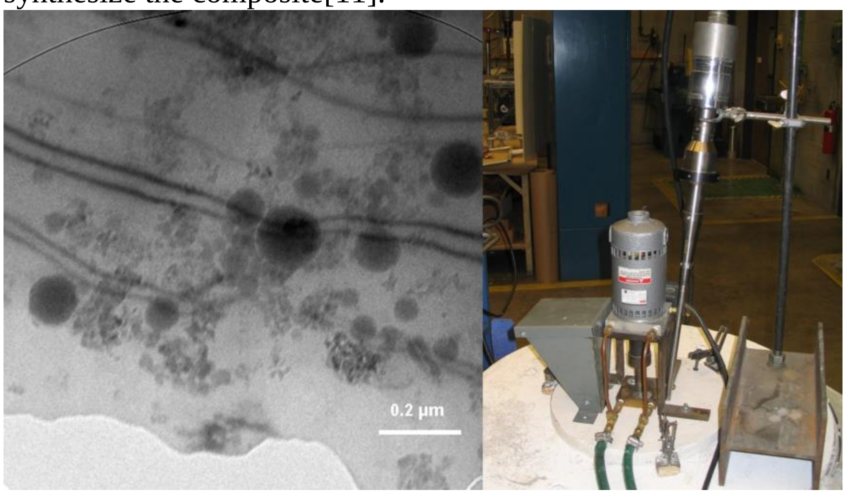

Fig. 3 — TEM of cast 47-nm (avg.) alumina-reinforced aluminum metal-matrix nano-composites produced at UWM[11].

Fig. 4 — Automotive components made of aluminum- and magnesium-fly ash composites developed at UWM[12].

Accessories

For components not exposed to extreme loading, further cost and weight reductions can be realized by incorporating fly ash (a waste by-product of coal power plants) in metal (e.g., aluminum, magnesium, lead, and zinc) matrices. Replacing components such as A/C pump brackets, timing belt/chain covers, alternator housings, transmission housing, valve covers, and intake manifolds (Fig. 4) with aluminum-fly ash composites can reduce the vehicle cost and weight, and thereby improve emissions and save energy[12, 13]. Adding fly ash to aluminum also reduces its coefficient of thermal expansion and increases its wear resistance along with making lighter and less expensive material.

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 result in a syntactic 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 syntactic foams being developed at UWM (Fig. 5) 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[14, 15].

In advanced automotive applications, syntactic foam can also serve as a core material to increase rigidity of thin-gage sheet metal sandwich structures, where high performance materials such as Kevlar honeycomb core material is cost prohibitive.

Fig. 5 — Aluminum-fly ash cenosphere syntactic foam (micrograph inset) within a steel frame. Courtesy of Bob Purgert.

Suspension

Many automakers started to use aluminum and light-gage 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) reinforced aluminum or aluminum nano-composites can further improve aluminum alloy designs by improving strength characteristics similar to cast iron, while using less material than similar aluminum arms. Self-lubricating graphite-reinforced aluminum bushings can also be incorporated into control-arm castings to allow for components that do not require service and will last the life of the vehicle.

Brakes

Automotive disk brakes and brake calipers, typically made of cast iron, are an area where significant weight reduction can be realized. SiC-reinforced aluminum brake rotors are incorporated in vehicles such as the Lotus Elise, Chrysler Prowler, General Motors EV1, Volkswagen Lupo 3L, and the Toyota RAV4-EV[5]. Widespread use of aluminum composite brake rotors requires their costs to come down and improved machinability. UWM developed aluminum-silicon carbide-graphite composites, aluminum-alumina-graphite, and hypereutectic aluminum-silicon-graphite alloys with reduced silicon carbide to help overcome cost and machinability barriers. Aluminum-fly ash composites developed at UWM have been explored to make prototype brake rotors in Australia[13].

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.

Battery

In attempts to reduce the weight of lead-acid batteries, UWM synthesized lead-hollow cenosphere composites with a density close to one half that of lead (Fig. 6). Work is underway to increase the corrosion resistance and conductivity of lead-cenosphere composites to acceptable levels[17].

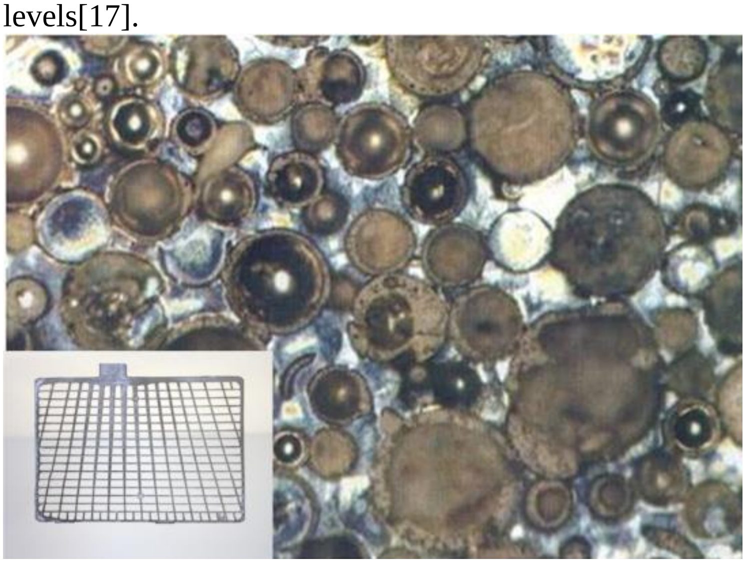

Fig. 6 — Lead-fly ash composites for battery applications made by pressure infiltration at UWM with typical lead-battery grid (inset).

Reliability, survivability, and reduced maintenance

UMW is developing engineered materials with self-repairing capabilities similar in concept to healing in biological systems[16]. These so-called self-healing materials are a new class of material that, either by outside influence or autonomously, repairs damage such as cracks and voids. Several techniques are used to impart a self-healing characteristic to metals, including specialized heat treatments and incorporation of shape memory-alloy wires that can “remember” their shape; when stretched across a crack, they are heated to pull the edges of the crack together[18] as it returns to its original shape (Fig. 7a). Another technique includes incorporating microtubes or microballoons containing a low-melting alloy within the matrix of a high-melting casting, which upon cracking, “burst” to allow the lower melting alloy to fill and seal the intruding crack[16].

Self-healing was demonstrated in polymeric and ceramic materials, and UWM is working on developing self-healing in metallic materials by incorporating long and short fibers of shape-memory alloys and microballoons and microtubes filled with low-melting healing alloys (Fig.7) These self-healing materials can help enhance the survivability of automobiles and lead to reduced maintenance and increased reliability.

UWM is also developing superhydrophobic metal-matrix composites and surface treatments on conventional alloys including nanostructured coatings, to have self-cleaning components that can lead to increased safety and reduced maintenance in automobiles.

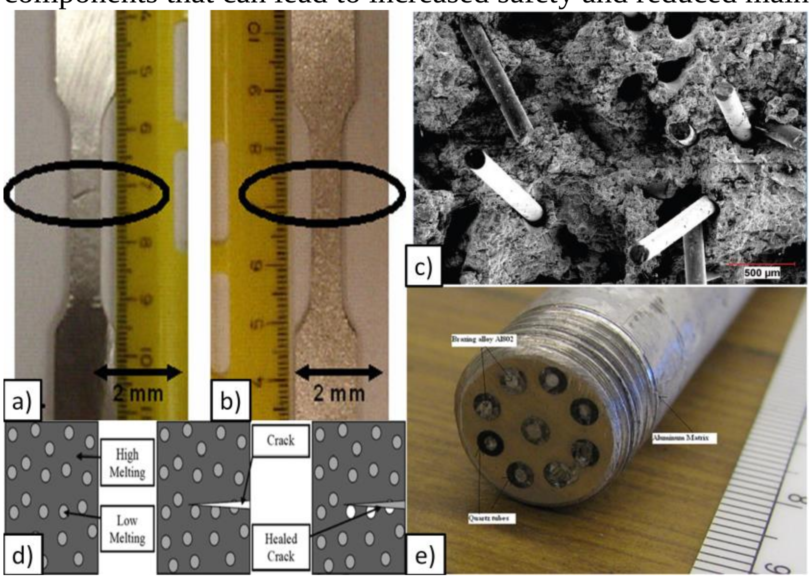

Fig. 7 — (a) Shape-memory alloy (SMA) wire-reinforced tensile bar with crack[18]; (b) SMA wire-reinforced tensile bar with healed crack[18]; (c) SEM image of fractured surface showing NiTi SMA wires extending from the crack surface in a Sn-20% Bi matrix; (d) schematic of self-healing metal using an encapsulated low-melting point phase; and (e) aluminum composite containing quartz tubes filled with an aluminum brazing alloy[16].

Conclusion

As automakers strive to meet imposed fuel economy and emissions regulations while producing vehicles with the quality and amenities consumers expect, the industry needs to rely on advancements made in the field of metal-matrix composites. By using materials developed at the Center for Composite Materials and Center for Advanced Materials Manufacture at the University of Wisconsin-Milwaukee, the auto industry can customize high-strength, wear-resistant, and self-lubricating lightweight MMCs for specific applications to make significant weight reductions and improve fuel efficiency.

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