High-Performance Polymer/Metal Composite Replaces Lead

A new injection-moldable thermoplastic composite can be formulated to meet the density, mass, and radiation-shielding properties of lead, while offering superior strength and design flexibility. Most important, unlike lead, it is nontoxic.

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For more than 6000 years, lead has been used for everything from icons and decorative items, water tanks, bearings, coins, pipes, and coffins, to a weapon (lead in its molten state) long before firearms shot bullets. Lead and lead alloys were used for casting movable type for printing, for caulking, for fastening bolts in masonry (still done today), and for dozens of everyday needs. Its low melting point and malleability made it easy to form lead into a multitude of useful shapes. Before long, however, lead was found to have toxic effects on humans, though little was done to prevent lead poisoning until quite recently.[1]

Despite its drawbacks, lead is still used. The metal effectively absorbs radiation and thus is used in medical and nuclear-power shielding applications. The ease with which it is formed, combined with its high density, continues to make lead an occasional choice for weights, ballast systems, and other applications in which mass and geometry dictate a need.

The fact remains, however, that lead has both short-term and long-term toxic effects. It ranks number one on the U.S. Environmental Protection Agency's list of top 20 hazardous substances. The state of California currently mandates public notification of hazardous substances in products produced or shipped in California, under the California Environmental Protection Agency Proposition 65. On the list are lead compounds and lead acetate. The action by California has preceded similar actions by other states and by the U.S. government on a nationwide scale.

Lead can be ingested, inhaled, and absorbed through the skin, and is (like many heavy metals) difficult to eliminate from the body. It affects the central nervous system, kidneys, cardiovascular system, and red blood cells. In addition to these dangers from elemental lead, the highly reactive metal readily generates toxic lead-based compounds. For example, lead oxide forms quickly upon exposure to air, and toxic levels of lead acetate can leach from the metal and from improperly fired lead-oxide-based ceramic glazes within a few minutes of exposure to orange juice and wine.

Fortunately, a thermoplastic tungsten/polymer composite has been developed with characteristics that preserve the performance attributes of lead (radiation absorption, ease of forming, and mass/weight) while avoiding its toxicity. With density equal to that of lead, this new material offers greater yield strength than lead, can be injection molded, is nontoxic, and can be formulated to be very flexible or very stiff, depending on the application. In addition, the new material has gamma and X-ray radiation-shielding properties similar to those of lead. Since this material incorporates a thermoplastic binder, it can be processed on conventional processing equipment, which enables it to be molded into virtually any three-dimensional shape. Because it is nontoxic, it can be handled, processed/fabricated, and recycled without detriment to people or the environment.

The properties of the new material, its applications, and its characteristics relative to lead will be examined.

Properties

Composed primarily of tungsten, plus a variety of types of polymer binders, the new poly/metal composite[2] is fully capable of being processed with conventional thermoplastic injection molding equipment. Different choices of polymer binders and levels of filler yield compounds whose densities range

Table 1. Select Characteristics of Seven Forms of the New Material. (Characteristics Vary by Percent Filler and Resulting Density.)

Property (Test)	Units	SF-79TP	SF-87TP	SF-92TP	NJ-84TP	NJ-90TP	NJ-94TP	NJ-96TP
Filler	%	79	87	92	84	90	94	96
Density (D-792)	g/cc	5.0	7.0	9.0	5.0	7.0	9.0	11.0
Flexural Modulus (D-790)	MPa	5860	6900	11,030	3000	3100	4310	8410
Tensile Strength (D-638)	MPa	41	59	66	50	50	52	52
Ultimate Elongation (D-638)	%	<1.0	<1.0	<1.0	4.5	3.0	2.0	<1.0
Notched Izod Impact (D-256)	J/m	32.09	42.78	48.13	58.82	58.82	69.52	77.54
Deflection Temp. 1.8 MPa (D-648)	°C	175	170	160	147	149	155	155
Linear Mold Shrinkage (D-955)	mm/mm	0.177	0.127	0.076	0.254	0.229	0.127-0.177	0.127-0.177

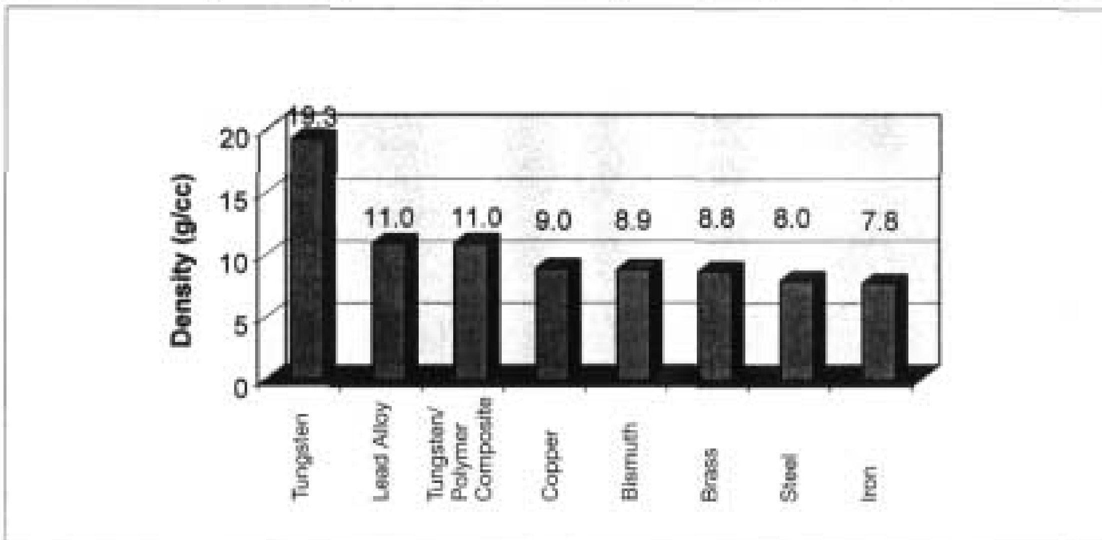

Figure. Density of the new tungsten/polymer composite vs. common metals.

from 2 g/cc on the low end to 11 g/cc on the high end. In its higher-density forms, the new composite is similar in behavior (except in toxicity) to the heavy metals, primarily lead, and also to other traditional materials such as lead alloys, brass, silver, and molybdenum.

Selected data for seven versions of the material, with densities ranging from 5 to 11 g/cc, are listed in *Table 1*.

Health and Safety Hazards

Material Safety Data Sheet (MSDS) information reveals generally no toxicity or health hazards from handling the poly/ metal material or from exposure to it. The composite exhibits the following characteristics:

- It is insoluble in water.
- It has a flash point of >400°C.
- A fire can be extinguished with any cooling or oxygen-excluding method.

• It presents no unusual fire or explosion hazard.
• Since it is inert, it has no health-hazard threshold limit value.
• It contains no carcinogenic agents.
• It is stable in terms of reactivity (although it is incompatible with strong oxidizing agents and fluorine gas).
• It is not classified as toxic waste if spilled or leaked as supplied.
• No respiratory protection is required; gloves and eye protection are routinely recommended during processing.

Density

Different base polymeric binders and levels of filler can be combined to create compounds with densities ranging from 2 to 11 g/cc. Using a formulation containing 96% filler by weight that has an 11-g/cc density as the baseline, the *Figure* compares the density of the new material with those of traditional, high-density metals.

Characteristics of Tungsten

A shiny white metal in its purest form, tungsten has a melting point of 3400°C (the highest of all elements with the exception of carbon), with good high-temperature

Table 2. Radiation Shielding of New Material vs. Lead.

Radiation Source (magnitude)	Test Apparatus or Detector	New Material Shielding (Lead = 100)
125 keV X-rays (10 milliamp-sec)	Average densitometer readings – exposure on standard radiographic film	92
Iodine 129 (39.6 keV γ)	HPGe	100
Xenon 133 (0.346 MeV β^-, 81.0 keV γ)	Gas Flow	100
	HPGe	100
	Victoreen (on contact)	100
	Victoreen (at 1 ft)	100
	Ludlum 9 (w/ beta shield)	100
	Ludlum 9 (w/o beta shield)	100
Thallium 201 (167.4 keV γ, 135.3 keV γ)	Gas Flow	100
	HPGe	98
	Victoreen (on contact)	99
	Victoreen (at 1 ft)	99
Technetium 99m (0.435 MeV β^-, 140.5 keV γ)	Gas Flow	100
	HPGe	99
	Victoreen (on contact)	99
	Ludlum 17 (w/beta shield)	100
	Ludlum 17 (w/o beta shield)	100
Phosphorus 332 (1.709 MeV β^-)	Gas Flow	100
	Victoreen (on contact)	98
	Victoreen (at 1 ft)	97
	Ludlum 17 (w/beta shield)	97
	Ludlum 17 (w/o beta shield)	100
Iridium 192 (0.672 MeV β^-; 4468.1 keV γ, 316.5 keV γ)	Gas Flow	96
	HPGe	91
	Victoreen (on contact)	87
	Victoreen (at 1 ft)	88
	Ludlum 9 (w/ beta shield)	92
	Ludlum 9 (w/o beta shield)	96
Fluorine 18 (0.635 MeV β^+, 511 keV γ peak used for measurement)	HPGe	90
	Victoreen (on contact)	83
Gold 198 (0.962 MeV β^-, 411.8 keV γ)	Gas Flow	100
	HPGe	87
	Victoreen (on contact)	87
	Victoreen (at 1 ft)	85
	Ludlum 17 (w/ beta shield)	85
	Ludlum 17 (w/o beta shield)	80
Cobalt 60 (318 MeV β^-, 1332.5 keV γ, 1173.2 keV γ)	Gas Flow	107
	HPGe	109
	Victoreen (on contact)	106

mechanical properties and the lowest coefficient of expansion of all metals. With a density of 19.3 g/cc, it is among the heaviest metals. Primary uses include hard metal alloys (including tungsten carbide), steel alloying, incandescent lighting filaments, electrical/electronic contacts, wire, and rod. The name itself is of Swedish origin—tung (heavy) and sten (stone)—in honor of the nationality of the chemist/ mineralogist who first discovered and described the ore. It is also known as wolfram, which gives it the chemical symbol W.

The new composite benefits from tungsten's density, inertness, and relatively low impact on the environment.[3]

Radiation Shielding

Table 2 indicates the radiation shielding capabilities of the new material at a density of 11 g/cc in relation to lead. In this Table, the radiation shielding of lead equals 100. Note the high values of the new material; in most cases, a slightly thicker layer of the new material can compensate for shielding shortfall.

Applications

Target applications for the new material include a large number of current applications for lead and other heavy metals. These include nontoxic projectiles and shot, radiation shielding for nuclear medicine/radiology and nuclear power, counterweights, sporting goods, ballast systems, vibration dampening, soundproofing, and many other applications for which a nontoxic, high-density, high-strength material is required.

Projectile and Shot

Ammunition projectiles represent a large market for the material. The U.S. Army alone fires approximately 689 million training rounds of small arms ammunition annually, amounting to nearly 1800 tons of lead per year. Lead contamination of soil, sediments, and surface and groundwater requires expensive remediation. The current U.S. Department of Defense remediation liability exceeds $9 billion. More than 100 outdoor ranges are closing or are scheduled for closing as a result of this problem and the associated cost of cleanup, and more than 1100 indoor ranges have been closed.

The new material would supply a nontoxic, lead-free replacement for bullet cores, with realistic performance and accuracy compared with conventional lead ammunition. The U.S. Army has completed its final testing of the new material for "green bullets" for 5.56 mm ammunition.

The 49,000 tons of lead used annually for sports and other nonmilitary purposes became an environmental problem. The use of lead shot for hunting migratory waterfowl has been prohibited in the U.S. since 1991. In 1999, Canada banned the use of lead shot. Most European countries also ban lead shot for hunting and lead weights for fishing tackle.

Radiation Shielding

Testing carried out at Texas A&M University indicates that the new material performs well as a shielding medium for both X-ray and gamma-radiation exposure (see *Table 2*). The new material is suited for applications such as the following:

- Nuclear power plants
- Medical imaging
- Nuclear medicine
- Industrial and medical X-ray tube housings
- Bitewing X-ray shields
- Radioisotope shipping containers
- Patient shields

One important subset of shielding applications is the control of mixed toxic and nuclear waste. Found at some 49 sites in 22 states in the U.S. alone, "mixed waste" is an especially difficult problem facing many different industry segments. Site-treatment plans require that waste be managed for both its radioactive and its toxic/hazardous characteristics.[4] The new tungsten/polymer composite may well contribute to solutions for this growing need by providing a medium for stabilization/encapsulation or by providing simple, nontoxic, and nonreactive shielding.

In addition, research and development is under way to optimize a formulation for shielding individual isotopes. One formulation has been developed, which has been tested at the University of Texas at Austin, that provides a cobalt-60 shielding equivalency to lead of 88% (1173 keV g) and 95% (1332.5 keV g). A unique aspect of this particular formulation is that this level of shielding is accomplished with a material density only 62% of that of lead.

Weighting and Ballast Systems

With its high density and resistance to corrosion and other kinds of environmental breakdown, the new material will perform well as a weighting material in applications where material mass is the primary need. These include the following:

- Flywheels
- Ballast systems
- Writing instruments
- Equipment stabilization and center-of-gravity control
- Aviation wing balancing
- Load testing
- Counterbalancing
- Sporting goods weighting systems (e.g., golf club heads and tennis racquet balance)

Because it can be supplied in pellet form as well as injection molded into any custom shape, the new poly/metal composite retains all the diversity of lead with the added benefit of being nontoxic.

Miscellaneous

The compliance and hardness of the new material can be modified by tailoring the formulation, adding new capability to passive vibration dampening, where both mass and energy absorption through flexure can play a critical part. In addition, sheer mass can absorb sound, especially in the lower frequencies, leading to a range of applications in construction, acoustic, and traffic engineering.

Conclusions

A new, nontoxic, poly/metal composite formed primarily of tungsten and polymeric resins can be used in a wide range of applications in which lead and other toxic heavy metals have been historically applied. Compared with lead, the new material offers greater yield strength, can be injection molded, is nontoxic, and can be formulated to address a variety of physical property requirements and a range of specific gravities, adding increased design flexibility. With a wide range of applicability, from radiation shielding to weighting and balancing, the new material represents an ecologically sound alternative to toxic, environmentally undesirable traditional materials.

Notes and References

1. R. Lansdowne and W. Yule, editors, *Lead Toxicity: History and Environmental Impact*, Baltimore, Johns Hopkins University Press, 1986, and J.O. Nriago, *Lead and Lead Poisoning in Antiquity*, New York, 1983.

2. The new material is compounded by PolyOne Corp. (formerly M.A. Hanna Engineered Materials) under license from Ideas to Market, L.P., Austin, Tex., and is marketed as ECOMASS resin. Ideas to Market, L.P., has applied for domestic and international patent protection for this material.

3. Information from the International Tungsten Industry Association (London).

4. U.S. Department of Energy, "Executive Summary for the National Summary Report of Draft Site Treatment Plans," available on-line at http://www. em.doe. gov/nsrodstp/execsum.html