NEW POLYMER-METAL COMPOSITES PROVIDE RADIATION SHIELDING, LEAD REPLACEMENT FOR MEDICAL DEVICES

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INTRODUCTION

A new polymer-metal composite has been developed to replace lead in a variety of medical devices, especially in radiation shielding and nuclear medical applications. This product is injection moldable and has similar radiation-shielding properties as lead, without the toxicity and disposal issues. Target applications include X-ray tube housings, radioisotope containers, syringe shields, bitewing dental X-ray packets, and shielding for technicians and patients. Testing at Texas A&M University has confirmed the potential of this new material's shielding properties.

The thermoplastic material can be compounded using a variety of polymers and fillers and can be formulated to meet and exceed key physical properties of lead. A primary advantage of this material is that it can be processed on conventional injection- and compression-molding equipment enabling processors to take advantage of the benefits of thermoplastic fabrication capabilities. Additional advantages include improved design flexibility and the use of only non-toxic constituents. To meet individual customer demands, it can be custom formulated to deliver alternative ranges of density (2.0-11.0 g/cc), impact strength, tensile strength, and heat-deflection temperatures. It can also be plated or powder-coated to improve appearance and wear resistance. The use of this material can eliminate substrates and support castings, as well as significantly reduce labor costs, all of which can translate into reduced shielding costs. Furthermore, use of this material eliminates the environmental, fabrication, and disposal issues related to lead.

ECOLOGICAL & TOXICOLOGICAL IMPLICATIONS

Lead, because of its cost and radiation shielding capacity, has traditionally been used in medical settings for technician and patient protection in X-ray facilities, nuclear medicine, and equipment containers and for housings. Unfortunately, offsetting the benefits, lead has poor mechanical properties, and the metal and its oxides and compounds are toxic, a characteristic that has been known since antiquity [1]. Increasingly since late in the 19th Century, lead usage has been restricted – in fact, virtually prohibited in any case of direct human or animal contact – by an ever-tightening set of regulations and laws. Costs for mining, smelting, and transport during material development; for handling and fabricating during product manufacturing; and for encapsulating lead in final products have all become quite burdensome owing to strict regulatory guidelines. Increasingly, regulatory burdens and handling costs have begun to impact every use of the material, including, of course, uses in medicine, where every effort must be taken to prevent patient exposure to toxic substances or iatrogenic disorders. In addition, disposal and ancillary remediation costs continue to have impact on virtually every segment of society.

One state, California, requires public notification of hazardous substances in products produced or shipped in California, under its California Environmental Protection Agency Proposition 65. Lead compounds and lead acetate are all emphatically included. Historically, such action by California has preceded similar action by other states and by the U.S. on a national scale.

Cumulatively, the performance attributes of lead and lead-based compounds in nuclear medicine should not be underestimated. According to the Society of Nuclear Medicine, the specialty – little known 50 years ago – has evolved into a major branch of medicine. More than 3,900 hospital-based nuclear medicine departments are employed in the U.S., performing more than 10-million nuclear magnetic imaging and therapeutic procedures each year, not including X-ray procedures [2]. In addition many thousands more X-ray departments exist, and hundreds of thousands of dental X-ray units are in operation worldwide.

Fortunately, a new material with the shielding capacity of lead has been developed. A polymer-metal (poly metal) composite of various thermoplastic resins, tungsten and other non-toxic components, the material is marketed under the name Ecomass™ resin [3]. Essentially inert chemically, the new material poses no toxic or ecological threat and can be successfully (and safely) recycled at the end of a product's life. This paper will examine some of the properties of the new material in relation to nuclear medicine and discuss potential medical applications.

PROPERTIES

Comprised primarily of tungsten plus a variety of types of polymer binders, the new poly metal composite is fully capable of processing with conventional thermoplastic injection molding equipment. Different choices of polymer binders and level of fillers yield compounds whose densities range from 2.0 g/cc on the low end to 11 g/cc on the high end (the same as lead). It is in the higher density forms that the new composite is similar in behavior to the heavy metals, primarily lead, but also lead alloys, zinc, brass, silver, and molybdenum.

Selected data for 7 versions of the material with various filler levels and densities ranging from 5-11 g/cc are given in Table I.

Table I – Select characteristics of 7 forms of the new material, which vary by % filler and resulting density.

Property (Test)	Units	SF-79TP	SF-87TP	SF-92TP	NJ-84TP	NJ-90TP	NJ-94TP	NJ-96TP
Filler (by weight)	%	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)	psi	850,000	1,000,000	1,600,000	435,000	450,000	625,000	1,220,000
Tensile Strength (D-638)	psi	5,900	8,500	9,500	7,300	7,300	7,500	7,565
Ultimate Elongation (D-638)	%	<1.0	<1.0	<1.0	4.5	3.0	2.0	<1.0
Notched Izod Impact (D-256)	ft-lb/in.	0.6	0.8	0.9	1.1	1.1	1.3	1.45
Deflection Temperature 264 psi (D-648)	°F (°C)	347 (175)	338 (170)	320 (16)	297 (147)	300 (149)	311 (155)	311 (155)
Linear Mold Shrinkage (D-955)	In./in.	0.007	0.005	0.003	0.010	0.009	0.005 – 0.007	0.005-0.007

Health and Safety Hazards

The primary component of the new material, the metal tungsten, was selected for its density and overall lack of reactivity and toxicity [4]. The polymer components of the composite consist of resins long approved for medical applications. Material safety data sheet (MSDS) information developed for the new material shows its resulting lack of toxic or health hazards. Critical parameters are as follows:

- Not classifiable as toxic waste if spilled or leaked as supplied
- Insoluble in water
- No unusual fire or explosion hazard
- Flash point of >400°C
- Extinguishable with any cooling or oxygen-excluding method
- No health hazard threshold limit value; product is inert
- No carcinogenic agents
- Stable in terms of reactivity (is incompatible with strong oxidizing agents and fluorine gas)
- No respiratory protection is required; gloves and eye protection are routinely recommended during processing

Density

Using the poly metal composite with 11 g/cc density as the baseline, Figure 1 compares the new material's density with those of various metals.

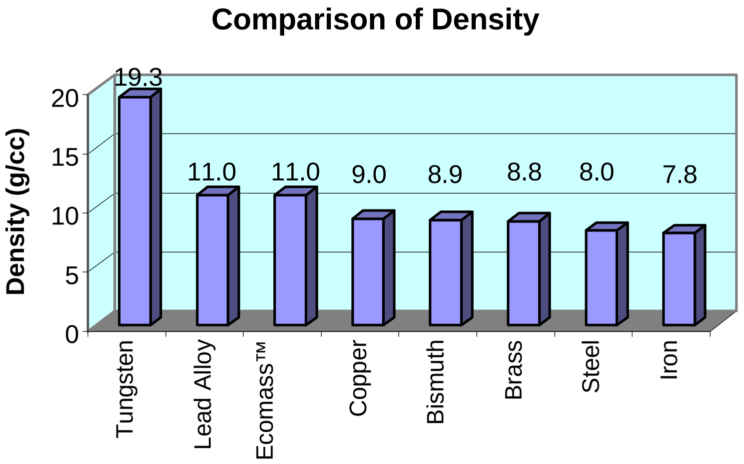

Figure 1 – Comparison of the density of the new material with those of common metals. The new polymer/tungsten composite's density of 11 g/cc matches that of generally available lead alloys (pure lead is 11.3 g/cc.)

The effectiveness of radiological shielding is to a large extent determined by density, radiation absorption of the filler materials and molecular or crystal structure. The new material has been developed to approximate those of lead, and testing by Texas A&M University has corroborated its ability to shield common forms of radioisotopes, gamma radiation, and X-rays.

Radiation Shielding

Table II lists the radiation shielding capabilities, in relation to lead, of the new material at density 11.0 g/cc; in this table, the performance of lead equals a value of 100. Note the high values of the new material. A useful design feature is that using a correspondingly thicker layer of the new material can often compensate for shielding shortfalls.

Table II – Radiation shielding of new material vs. lead (lead = 100)

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

APPLICATIONS

Target medical applications for the new poly-metal composite include the following:

- X-ray tube housings
- Equipment housings and castings
- Radioisotope containers
- Syringe shields
- Bite-wing dental X-ray packets
- Technician and patient shielding

The human shielding and dental X-ray packet shielding is fairly straightforward, and will most likely use the material in sheet or film form. Tube housings, radioisotope containers, and similar applications will be able to take advantage of the fact that the new material can be processed in any conventional thermoplastic molding machine. Molded into virtually any custom three-dimensional geometry and wall thickness, the new material will be able to provide shielding even for the most tightly constrained, space-conscious application, a benefit for instrument and container producers who must contend with ever-shrinking product footprints.

Because of the ability to fine-tune physical properties, including density, impact strength, tensile strength, and heat-deflection temperature, the new material will permit great flexibility in applications and designs. Medical equipment is undergoing the same trend toward “soft sculpted” forms that can be found in automobile design (and in industrial design in general), and designers must continue to wrap functional components in attractive and contemporary housings. Compression molding in particular could open up new design avenues, as layers of differing densities and properties could be incorporated, maximizing radiological shielding while minimizing weight and bulk. Finally, by tuning the mechanical properties of the material, significant reduction in substrates and support assemblies can be realized. The result is that designs can be realized with fewer components, and, where lead was once employed, manufacturers and end-users can bypass all of the expenses, special procedures, documentation, and regulatory pressures associated with lead.

Research and development is ongoing to optimize a formulation specifically for shielding individual isotopes. To date, one formulation has been developed, which has been tested at University of Texas at Austin, that provides a Cobalt-60 shielding equivalency to lead of 88% (1173 keV γ) and 95% (1332.5 keV γ). A unique aspect of this particular formulation is that this level of shielding is accomplished with a material density of only 62% of that of lead.

CONCLUSION

A new composite, consisting primarily of tungsten and thermoplastic polymers, can be used in a wide range of applications where lead (and various other toxic heavy metals as well) has been applied up to now. The new material offers greater yield strength, can be injection molded, is non-toxic, and can be formulated to a wider range of stiffness, from very flexible to very stiff, compared to lead. In addition, because the new material can be formulated to a wide variety of physical properties and a range of densities, designers will find new flexibility in designing shielding and equipment to fit ever-smaller footprints and ever more “styled” housings. The new material represents an ecologically and economically sound alternative to traditional materials that are toxic and increasingly environmentally undesirable.

NOTES AND REFERENCES

1. cf. Lansdowne, R. and Yule, W. editors, *Lead Toxicity: History and Environmental Impact*, Baltimore, Johns Hopkins University press, 1986. Also, Nriago, J.O., *Lead and Lead Poisoning in Antiquity*, New York, 1983.
2. Source: Society of Nuclear Medicine, 1999.
3. The new material is licensed by Ideas to Market, L.P. (Austin, TX) to M.A. Hanna Engineered Materials (Norcross, GA) and is marketed as ECOMASS™ resin. Ideas to Market, L.P has applied for domestic and international patent protection for this material.
4. A shiny white metal in its purest form, tungsten has the highest melting point of all elements except carbon, at some 3,400°C, with good high-temperature 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 deference to the Swedish chemist/mineralogist who first discovered and described the ore. It is also known as wolfram, which gives tungsten its chemical symbol, W. (Source: Tungsten Industry Association [London]). The new polymetal composite capitalizes on tungsten’s density, inertness, and relatively low danger to the environment.