Study Finds Metal Foams Capable of Shielding X-rays, Gamma Rays, Neutron Radiation

A sample of the composite metal foam developed in Rabiei's research group. Photo credit: Afsaneh Rabiei. Click to enlarge.

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Afsaneh Rabiei | 919.513.2674
Matt Shipman | 919.515.6386

Research from North Carolina State University shows that lightweight composite metal foams are effective at blocking X-rays, gamma rays and neutron radiation, and are capable of absorbing the energy of high impact collisions. The finding means the metal foams hold promise for use in nuclear safety, space exploration and medical technology applications.

"This work means there's an opportunity to use composite metal foam to develop safer systems for transporting nuclear waste, more efficient designs for spacecraft and nuclear structures, and new shielding for use in CT scanners," says Afsaneh Rabiei, a professor of mechanical and aerospace engineering at NC State and corresponding author of a paper on the work.

Rabiei first developed the strong, lightweight metal foam for use in transportation and military applications. But she wanted to determine whether the foam could be used for nuclear or space exploration applications – could it provide structural support, protect against high impacts and provide shielding against various forms of radiation?

To that end, she and her colleagues conducted multiple tests to see how effective it was at blocking X-rays, gamma rays and neutron radiation. She then compared the material's performance to the performance of bulk materials that are currently used in shielding applications. The comparison was made using samples of the same "areal" density – meaning that each sample had the same weight, but varied in volume.

The most effective composite metal foam against all three forms of radiation is called "high-Z steel-steel" and was made up largely of stainless steel, but incorporated a small amount of tungsten. However, the structure of the high-Z foam was modified so that the composite foam that included tungsten was not denser than metal foam made entirely of stainless steel.

The researchers tested shielding performance against several kinds of gamma ray radiation. Different source materials produce gamma rays with different energies. For example, cesium and cobalt emit higher-energy gamma rays, while barium and americium emit lower-energy gamma rays.

The researchers found that the high-Z foam was comparable to bulk materials at blocking high-energy gamma rays, but was much better than bulk materials – even bulk steel – at blocking low-energy gamma rays.

Similarly, the high-Z foam outperformed other materials at blocking neutron radiation.

The high-Z foam performed better than most materials at blocking X-rays, but was not quite as effective as lead.

"However, we are working to modify the composition of the metal foam to be even more effective than lead at blocking X-rays – and our early results are promising," Rabiei says. "And our foams have

the advantage of being non-toxic, which means that they are easier to manufacture and recycle. In addition, the extraordinary mechanical and thermal properties of composite metal foams, and their energy absorption capabilities, make the material a good candidate for various nuclear structural applications."

The paper, "Attenuation efficiency of X-ray and comparison to gamma ray and neutrons in composite metal foams," is published in *Radiation Physics and Chemistry*. Lead author is Shuo Chen, a recent Ph.D. graduate at NC State. The paper was co-authored by Mohamed Bourham, a professor of nuclear engineering at NC State. The work was supported by DOE's Office of Nuclear Energy under Nuclear Energy University Program grant number CFP-11-1643.

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Note to Editors: The study abstract follows.

"Attenuation efficiency of X-ray and comparison to gamma ray and neutrons in composite metal foams"

Authors: Shuo Chen, Mohamed Bourham and Afsaneh Rabiei, North Carolina State University

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Abstract: Steel-steel composite metal foams (S-S CMFs) and Aluminum-steel composite metal foams (Al-S CMFs) with various sphere sizes and matrix materials were manufactured and investigated for nuclear and radiation environments applications. 316 L stainless steel, high-speed T15 steel and aluminum materials were used as the matrix material together with 2, 4 and 5.2 mm steel hollow spheres to manufacture various types of composite metal foams (CMFs). High-speed T15 steel is selected due to its high tungsten and vanadium concentration (both high-Z elements) to further improve the shielding efficiency of CMFs. This new type of S-S CMF is called High-Z steel-steel composite metal foam (HZ S-S CMF). Radiation shielding efficiency of all types of CMFs was explored for the attenuation of X-ray, gamma ray and neutron. The experimental results were compared with pure lead and Aluminum A356, and verified theoretically through XCOM and Monte Carlo Z-particle Transport Code (MCNP). It was observed that the radiation shielding effectiveness of CMFs is relatively independent of sphere sizes as long as the ratio of sphere-wall thickness to its outer-diameter stays constant. However, the smaller spheres seem to be more efficient in general due to the fine fluctuation in the gray value profile of their 2D Micro-CT images. S-S CMFs and Al-S CMFs are respectively 275% and 145% more effective for X-ray attenuation than Aluminum A356. Compared to pure lead, CMFs show adequate attenuation with additional advantages of being lightweight and more environmentally friendly. The mechanical performance of HZ S-S CMFs under quasi-static compression was compared to that of other classes of S-S CMF. It is observed that the addition of high-Z elements to the matrix of CMFs improved their shielding against X-rays, low energy gamma rays and neutrons, while maintained their low density, high mechanical properties and high-energy absorption capability.