A new way to test body armor

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Credit: AI-generated image (disclaimer)

Scientists at the National Institute of Standards and Technology (NIST) have developed a new way to investigate the high-performance fibers used in modern body armor. Described in the *Journal of Polymer Science*, the research may help increase confidence in the apparel that protects military units, police departments and public figures from gunfire. It may also lead to the development of new, lighter weight materials for body armor in the future.

High-performance polymer fibers have been used in ballistics applications for more than 40 years. Traditionally, these fibers are woven together into a fabric and then layered 15-20 times over to make a vest with a thickness of anywhere from about 6 to 13 millimeters (a quarter to half an inch). Although effective at stopping or slowing down bullets, users have sometimes found these vests, which are worn either under or over clothing, to be heavy and bulky—akin to wearing 15 to 20 shirts at once on a hot summer day. Many would like a more comfortable alternative.

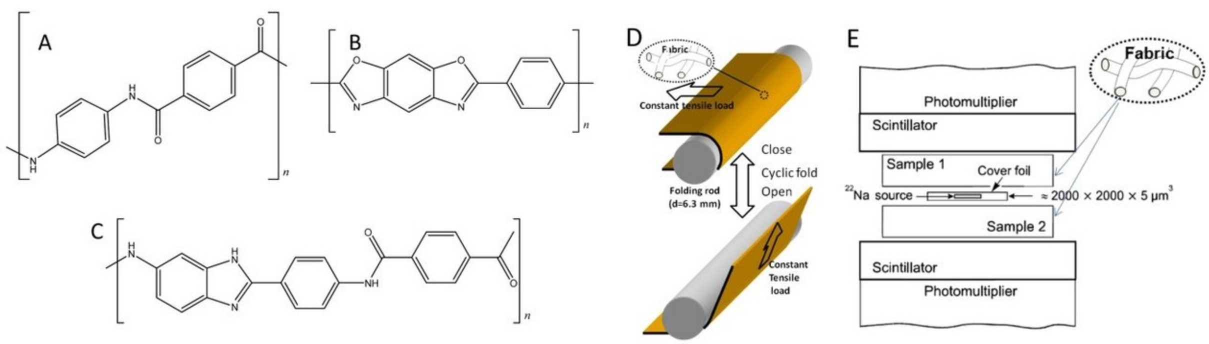
The testing of soft body armor has been a big concern because the deployment of a new kind of fiber—believed to be superior to the previous material—unexpectedly failed in 2003, resulting in the death of a police officer. That and other incidents prompted a 2005 recall of some of the vests made with the new material.

Although the performance of these vests was superior when they were fresh out of the box and in pristine condition, tests later showed that the mechanical properties of the fibers inside the vests began to deteriorate after a few months of normal wear. The new vests were eventually removed from market entirely and the manufacturer was sued by the Department of Justice (DOJ).

The DOJ enlisted NIST to help evaluate the problem and determine why these vests were failing. As the nation's measurement lab, NIST researchers are especially qualified to develop ways to characterize both the fibers and their eventual deterioration.

"The fibers in these ballistic applications cannot fail [in the field], period," said Gale Holmes, a materials research engineer at NIST. "But previously, we had no way to know if they were changing over time as people were wearing and using them."

The ideal mechanical properties for these vests and other gear include a combination of high stiffness, large tensile strength, and a significant strain-to-failure in order to absorb the impact of the bullet. Initial work by Holmes revealed that the natural creasing and folding that a vest would normally encounter while in use led to a significant degradation of these critical mechanical properties, especially in humid environments.



Chemical structure of the (A) PPTA, (B) PBO, and (C) poly(p-phenylene benzimidazole terephthalamide-co-p-phenylene terephthalamide) (PBIA-co-PPTA) materials used in body armor. Schematic of the fabric folding method for aging ballistic fiber cloths (D) and schematic of positron annihilation lifetime spectroscopy (PALS) setup for measuring the materials. Credit: J.A. Howarter et al., Journal of Polymer Science

While the degradation in the mechanical properties was self-evident, what was missing was an analytical technique to characterize the structural or chemical differences in the fibers that would account for their loss in performance. Although there is no material that could be completely "bulletproof" in every circumstance, researchers did want a way to characterize materials for their varying ability to mitigate a bullet's impact, especially after field use.

The characterization method selected by Holmes and Christopher Soles at NIST made use of an intense positron beam facility at North Carolina State University's PULSTAR Nuclear Reactor.

The positron annihilation lifetime spectroscopy (PALS) technique provides a molecular-level view of the structure of materials. It has been used for testing materials in other sectors, including porous membranes and semiconductor insulators. For this work, positrons were injected into ballistic fibers and enabled researchers to determine if any voids were created during folding on a scale of less than 5 nanometers.

Using PALS, Holmes and Soles discovered that void levels are very sensitive indicators of damage sustained by the fibers after folding; a larger population of voids means a better chance of fiber failure. The team previously suspected that void creation was a critical component of mechanical degradation, but the small angle X-ray scattering measurements that had been used in the past tended to be less sensitive to voids smaller than 5 nanometers and proved to be inconclusive. The critical damage was occurring on much finer length scales.

"It allowed us to characterize changes in the fibers that you cannot see with other techniques," Holmes said. "We were surprised during our research at how sensitive the technique was."

"Before, we didn't have a really good way to discriminate why some materials broke during folding tests and some didn't," said Soles. "This is the first materials characterization tool that gives insights into why some materials can be folded and still maintain their strength."

The results may act as a design cue for those wanting to develop new alternatives to the current body armor. It may also help fine-tune the amount of fibers currently prescribed for these products, making for more comfortable vests.

More information: John A. Howarter et al. Nanostructural evidence of mechanical aging and performance loss in ballistic fibers, *Journal of Polymer Science Part B: Polymer Physics* (2017). DOI: 10.1002/polb.24417

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