Army Research Laboratory developing poly(urethane urea) elastomers (PUUs) for combat helmets

Armor used to protect soldiers and vehicles has traditionally been comprised of ceramics, metals, or lightweight fiber-reinforced composites, which are typically based on stiffness (the resistance of a material against deformation) and toughness (the ability to absorb energy and plastically deform prior to fracture). The Army's current combat helmet is made of ultrahigh molecular weight polyethylene or UHMWPE fibers-based composites. These fibers have high breaking strength per unit cross section area—about 15 times stronger than steel—but are flexible like fabrics.

US ARL laboratoties have discovered new materials PUUs, polyurethanes, and similar elastomers that exhibit dynamic strengthening in high-rate deformations that limit deformations of the helmet under impact would make for better combat helmets. Scientists say their discovery on bulk elastomers can help design matrix materials for composites for the future generation of U. S. Army combat helmets.

Army Research Laboratory's Dr. Alex Hsieh, along with Prof. Keith A. Nelson, Dr. David Veysset and Dr. Steven Kooi, from the Army's Institute for Soldier Nanotechnology at MIT, discovered that when targets made of poly(urethane urea) elastomers or PUUs are impacted at very high speed by micro-particles made of silica, the PUU target shows hyperelastic behavior. That is, they become extremely stiff when deformed at strain rates on the order of 108/s which means roughly that the material of the target deforms to half of its original thickness in an extremely short time equal to one second divided by hundred millions. PUUs also quickly return to their original shape after the impact, said Hsieh.

The Army's enhanced combat helmet uses high performance ultrahigh molecular weight polyethylene or UHMWPE fibers based composites. These fibers have high breaking strength, per unit cross section area, about fifteen times stronger than steel but are flexible like fabrics. From the design perspective, the PUUs can be used as the helmet's outermost layers or to replace the polycarbonate shell.

In addition to combat helmets, other potential applications of robust high performance elastomers for Soldier protection include but are not limited to transparent face shields, mandible face shields, ballistic vests, extremity protective gear, and blast-resistant combat boots. On the civilian side, they could protect football players and young athletes against concussions and other brain-related injuries brought upon by collisions.

Poly(urethane urea) elastomers (PUUs)

Hsieh said the team focused on polymers, which are made up of a very large number of small molecular units that are strung together to form very long chains, which can be well organized or randomly packed. Specifically, polymeric materials that are strong like impact-resistant safety glasses or flexible like rubbers.

Elastomers are a class of human made rubbers, which can be synthesized from a broad range of polymer chemistries. "They generally have low Young's modulus which means low resistance to elastic deformation under loading at ambient conditions, and higher failure strain the capability to sustain significantly greater amount of strain before failure than most of the plastic materials," he explained.

Elastomeric polymers are promising materials for ballistic impact protection both on the macroscale (for example, in armour panels) and on the microscale, for example as protective coatings for helicopter rotor blades and in powder blasting. Among elastomer candidates for enhanced ballistic protection, polyureas, polyurethanes, and PUUs have recently gained interest owing to their versatile dynamic response. Because of the thermodynamic incompatibility between building blocks, these polymers present a complex morphology with domains having different degrees of microphase separation between hard and soft segments. Recent studies have indicated that the extent of phase–mixing strongly affects the segmental dynamics and the strain–rate hardening characteristics of PUUs.

“This is very exciting.” said Dr. Hsieh “Seeing is believing. New understanding from these research discoveries – the essence of hyperelastic phenomenon in bulk elastomers particularly at the moment of target/impulse interaction strongly points out to be a plausible pathway key to manipulating failure physics and towards a new design paradigm for robust materials.”

However, from the point of view of materials science, just these typical bulk metrics are not adequate to evaluate the speed with which the mobility of molecules in a polymer solid is changed in relation to deformation rate, as well as the tendency of modification of their respective physical state as part of the dynamic deformation. The question remains, do elastomers get modified from rubber-like to glass-like while being deformed at increasingly higher rates.

For further verification of the molecular effect, the Researchers performed elaborate research on PUUs together with a glassy polycarbonate. Whereas the polycarbonate has high ballistic strength and fracture toughness, the PUUs (in spite of their respective composition) were found to have higher dynamic stiffening upon being impacted at strain rates of

108/s. In addition, Researchers can optimize the resistance to micro-particle penetration, that is, approximately 50% decrease in the average maximum penetration depth was accomplished by just altering the molecular composition of the PUUs.

RICE & MIT University discover a nanostructured material that could stop bullets

IN 2013, A team of researchers of RICE and MIT University Jae-Hwang Lee, and others have found an extremely light, paper thin nanocomposite material polystyrene-polydimethylsiloxane diblock-copolymer, that could stop bullets as effectively as heavy weight armor like steel.

The team developed a 20 nanometer self assembling polymer which is structured as nanometer thick alternating rubbery layers, providing the reseliance and glassy layers providing the strength. The research was supported by the U.S. Army Research Office.

The team also developed a laser pulse based technique called laser-induced projectile impact test (LIPIT) for producing laboratory scale high speed ballistic impacts and observing their effects precisely. It involves shooting 3 nanometer glass beads at the material at high speed and observing its effects on the material using electron microscope. Using this technique they found that for sufficient high velocities the material melted into a homogeneous liquid that arrested the projectile and sealed its entry path.

The nanomaterial and the testing technology could accelerate the development of applications like materials for vehicle and body armor, protective coatings for satellites to shield from micrometeorite impacts; and coatings for jet engine turbine blades to protect from high-speed impacts by sand or ice particles.

References and Resources also include:

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