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# The Use of Metamaterials in the Advancement of Personal Protection and Body Armour

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For centuries, man has understood the need for personal safety, protection from the elements as well as from predators and even each other. This personal protection has ranged from animal skins and leather, iron plate armour and chainmail, to the more recent Kevlar and steel plating. Advancements have been made with the help of nanoscience, specifically in metamaterial and nanostructure material manufacturing. As a result, body armour has advanced to the new level needed to protect soldiers and law enforcement personnel from increasingly more devastating small arms weapon systems. Military forces all around the world are beginning to realize the potential that nanomaterials and nanocoatings have in various technological areas, especially in the area of armouring as personal protection (U.S. Army, 2010). Newly developed nanomaterials are now being used to strengthen armour systems for both soldiers and vehicles, with particular attention to reinforcing structures that are still light enough to allow ample mobility.

**Transition to nanomaterials**

The biggest material transition occurring right now in the area of personal protection and body armour is the substitution of ceramics for steel plating (Zhang, Kalia, Nakano, Vashishta & Branicio, 2008). Although ceramics help to increase the mobility of the wearer, traditional ceramic plates are brittle and fracture upon impact, making them less likely to maintain their structural integrity after several high-velocity impacts. This limitation presents a considerable threat in modern combat (Zhang et al.). Understanding how to counteract this problem begins with analysing the effects of multiple high velocity impacts on these new ceramic plates at a molecular level. Discovering how to formulate and manipulate the mechanical properties of the ceramics to make them stronger and more resilient promises not only to offer greater protection, but also to improve the soldiers' mobility. They are also less expensive to manufacture than alternative nanomaterials such as carbon nanotubes or graphene. Along with the obvious benefits of protecting soldiers from projectiles and blunt force trauma, ceramic nanomaterials have also been known to have a greater tolerance to extreme changes in both temperature and weather conditions (Papalardo, 2004). Soldiers can fight in poor conditions for longer periods of time without having to worry about the adverse effects the environment has on their equipment.

**Production of nanomaterials**

There are two main methods of producing and processing ceramic nanomaterials for use in personal protection and body armour. One method is to use electrospinning to create individual nanofibres and then weave them together; the other is to take a bulk sample of a natural or synthetic ceramic and alter its molecular structure in order to give it the desired properties. Both methods of production have their own advantages and disadvantages, but each strives to produce super-strong and resilient materials.

In electrospinning, a polymer solution containing the desired ceramic compound is pumped through an electric field produced by a DC current. Once the charge produced by the current is strong enough to break the surface tension of the solution extruded from a spinneret, the solution is pulled into long thin fibres and collected by a grounded collection plate (Ramaseshan, Sundarrajan, Jose, & Ramakrishna, 2007). By combining this method of producing nanofibres with a solute-based gel technique which produces various sizes of individual nanoceramic particles through a precipitation reaction, nanofibres with desirable characteristics such as exceptional flexibility and long-lasting breakage resistance can be obtained (Ramaseshan et al.). After they have been woven together using a magnetic field, the ability of the different fibres to deform and reduce impacts caused by projectiles can be determined by analysing their mechanical properties. Ceramic, in fibre form, has been found to have superior toughness and flexion strength, a measure of a fibre's resistance to twisting or bending, in comparison to Kevlar (Ramaseshan et al.). The benefits that these nanofibres have in terms of body armour are evident when developers and scientists analyse the molecular interactions between individual fibres.

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The second method of producing nanoceramics for use in personal protection and body armour is by taking a bulk sample of a natural ceramic, such as alpha-alumina which has an alpha-directed spin on its molecules, and altering its molecular structure by adding or removing certain compounds or molecules to give it the desired properties. In the case of body armour, these desired properties include increased compression and flexion strengths. These properties have been observed when EPON 828, a strong synthetic resin, has had its composition altered by adding various percentages of clay nanoparticles. Researchers at the Centre for Advanced Materials at the University of Tuskegee added 0.5%, 1.0%, 1.5% and 2.0% per unit mass which showed a gradual increase in the strength of the material (Hosur, Gebremedhin, & Jeelani, 2009). A bulk natural ceramic sample was altered in a similar way, and tested for changes in the tensile, flexion and compression strengths of the material. Better understanding of how the material reacts under multiple high velocity impacts at a nanoscopic scale was gained. These materials were shown to be equally as effective at slowing and even stopping projectiles in real world situations as they had seemed in the laboratory.

**Experimental testing**

In order to produce a protection system that can effectively stop high velocity projectiles, testing needs to be done on the tensile, compression and flexion strength of the material to find a point at which it will not fracture under a high velocity impact. When a high velocity projectile such as a bullet impacts a surface, one of two outcomes can occur. Either the majority of the kinetic energy from the projectile is maintained during the impact, allowing the projectile to pass completely through the substance; or a large amount of kinetic energy is absorbed by the surface itself, resulting in little or no penetration. In both situations, the material can fracture and break apart at the point of impact. If, however, the force is absorbed mainly by a surface such as a ceramic plate or a ballistic vest, the amount of force transmitted to the wearer is reduced, minimizing the chance of injury. Difficulty arises, however, if the surface is brittle and shatters into multiple fragments, producing gaps in the vest (Gonçalves, de Melo, Klein, & Al-Qureshi, 2003).

Both woven nanoceramic fibres and bulk ceramic samples are tested in a similar manner. One team tested the tensile strength of a bulk ceramic sample by using dog-bone shaped segments of the sample to which linear force was applied with a servo-hydraulic material testing system (Hosur et al., 2009). The team from NUS Nanoscience and Nanotechnology Initiative in Singapore used a similar three-point bending method to test the mechanical strength of the electro-spun nanofibres (Ramaseshan et al., 2007). The nanofibres that were being tested here were composed of titanium dioxide. Their compression strength was partially tested through the three-point bending test, although more direct testing of their compression strength has not yet been conducted. The alumina was tested by analysing the effects of nanoscopic, high-velocity impacts on a microscopic section of the sample material (Zhang et al., 2008). The compression effects of the impact at a nanoscopic scale enabled more accurate calculation of the results for a real world application from that of partial testing.

**Conclusion**

Based on previous research conducted, nanoceramics have been showing considerable potential as an alternative material for use in personal protection and body armour systems. Results from the tensile, compressive, and flexion tests as well as testing done on the nanofibres and the samples of alumina in its alpha state all showed that they could absorb force values well beyond that of traditional body armour. Testing of a sample of alpha-alumina using high velocity impacts from micro projectiles (Hosur et al., 2009) showed shock wave patterns on the surface of the tested samples which altered the molecular structure of the surface, causing it to fracture or warp. The forces at which the first alterations occurred were recorded and analysed. For aluminum nitride, a similar ceramic compound, it was calculated that 100 Giga Pascals would cause structural change, but testing alumina in its alpha state, revealed that it could absorb shock wave impacts up to 360 Giga Pascals before any signs of structural transformation or weakness was observed (Zhang et al., 2008). For nanospun fibres, a test polymer infused with nickel oxide particles had a significant increase in both toughness and hardness after spinning. Fracture resistance was increased by a factor of 1.8 times that of the control samples (Ramaseshan et al., 2007).

Nanoceramic materials, either bulk samples or woven fibres, show great potential in body armour systems. Their increased resilience and strength rivals that of steel while still maintaining lightweight properties and reduced bulk. These enhancements to body armour systems could potentially provide users with increases in both mobility and protection. This discovery has the potential to produce more effective personal protection and body armour systems, and as a result save more lives in both law enforcement and the military.

## References

Altmann, J., & Gubrud, M. (2004). Anticipating military nanotechnology. *Technology and Society Magazine, 23*(4), 33–40.

Gonçalves, D. P., de Melo, F. C. L., Klein, A. N., & Al-Qureshi, H. A. (2003). Analysis and investigation of ballistic impact on ceramic/metal composite armour. *International Journal of Machine Tools & Manufacture, 44*(2), 307–316. doi:10.1016/j.ijmachtools.2003.09.005

Hosur, V., Gebremedhin, O., & Jeelani, S. (2009). Processing and performance evaluation of Nanoclay infused EPON 828. *Polymers & Polymer Composites, 17*(3), 151–159.

Pappalardo, J. (2004). Military ponders future of nanotech. *National Defense, 89*(611), 24–25.

Ramaseshan, R., Sundarrajan, S., Jose, R., & Ramakrishna, S. (2007). Nanostructured ceramics by electrospinning. *Journal of Applied Physics, 102*(11), 111101-1–17. doi:10.1063/1.2815499

Tiny particles, huge impact: Nanotechnology to help warfighters. *States News Service,* 8 Oct 2010.

Zhang, C., Kalia, R. K., Nakano, A., Vashishta, P., & Branicio, P. S. (2008). Deformation mechanisms and damage in α-alumina under hypervelocity impact loading. *Journal of Applied Physics, 103*(8), 083508-1–15. doi:10.1063/1.2891797