Soft Body Armour: Not Just Science Fiction

Rok Nezic

Even though they might not catch as much public attention as Predator drones, smart bombs and intelligent robots, the developments in defensive technology that can protect soldiers against both old and new threats are no less fascinating and groundbreaking in many aspects. The introduction of steel helmets in World War I dramatically reduced death from head trauma [1], but from World War II through the Korean War, more than 70% of non-fatal injuries were those of limbs and as much as 16% of battle deaths were from trauma to extremities, rather than to the head or torso [2]. Protecting arms and legs has proven much more difficult than reinforcing the helmet, because of the inherently conflicting needs for mobility and rigidity.

> "The risk of limb injury has sharply increased in recent conflicts."

The risk of limb injury has sharply increased in the recent conflicts. Insurgents in Afghanistan and Iraq sometimes use makeshift bombs: little more than propane canisters packed with metal scraps, ball bearings or even glass, which can inflict very serious injuries [3]. Current body armour can stop both bullets and shrapnel from piercing a soldier's chest, but the Kevlar plates used are far too bulky and heavy to protect limbs [2]. The only reasonable way to do so is to provide armour light enough and flexible enough to cover the arms and legs—and still stop metal travelling at more than 100 metres per second.

Luckily, materials called shear-thickening fluids (STFs) have a potential answer already in the pipes. Their name may seem rather obscure, but in fact, many common substances exhibit properties of STFs. Some of the better-known examples of such materials are the childhood toy Silly Putty, quicksand and mixture of cornstarch and water, but blood is a STF as well, and ketchup and shampoos exhibit some similar properties, although they are actually shear-thinning fluids [4].

In many aspects, these viscous mixtures act like fluids: they fill the shape of the bottom of their containers and flow, albeit rather slowly. On the other hand, when stress is applied, these substances react like solids e.g., if one hits the surface of a corn starch-water mixture with a fist, one's hand does not move past the surface as if through water. This duality arises from unconventional phenomena occurring at the nano-scale of STFs, and offers a way to protect soldiers' limbs.

Shear-thickening fluids are mixes of colloids, which are microscopic particles in a liquid base [4]. For purposes of body armour use, these miniature spheres are usually made of silica, and reach less than 500 nanometres in diameter. Blending colloids into a stable fluid like ethylene glycol (common antifreeze) in appropriate concentrations creates a suspension as the liquid fills the gaps between the particles. As mentioned above, the suspension acts rather like a normal liquid in many aspects, although it requires some initial

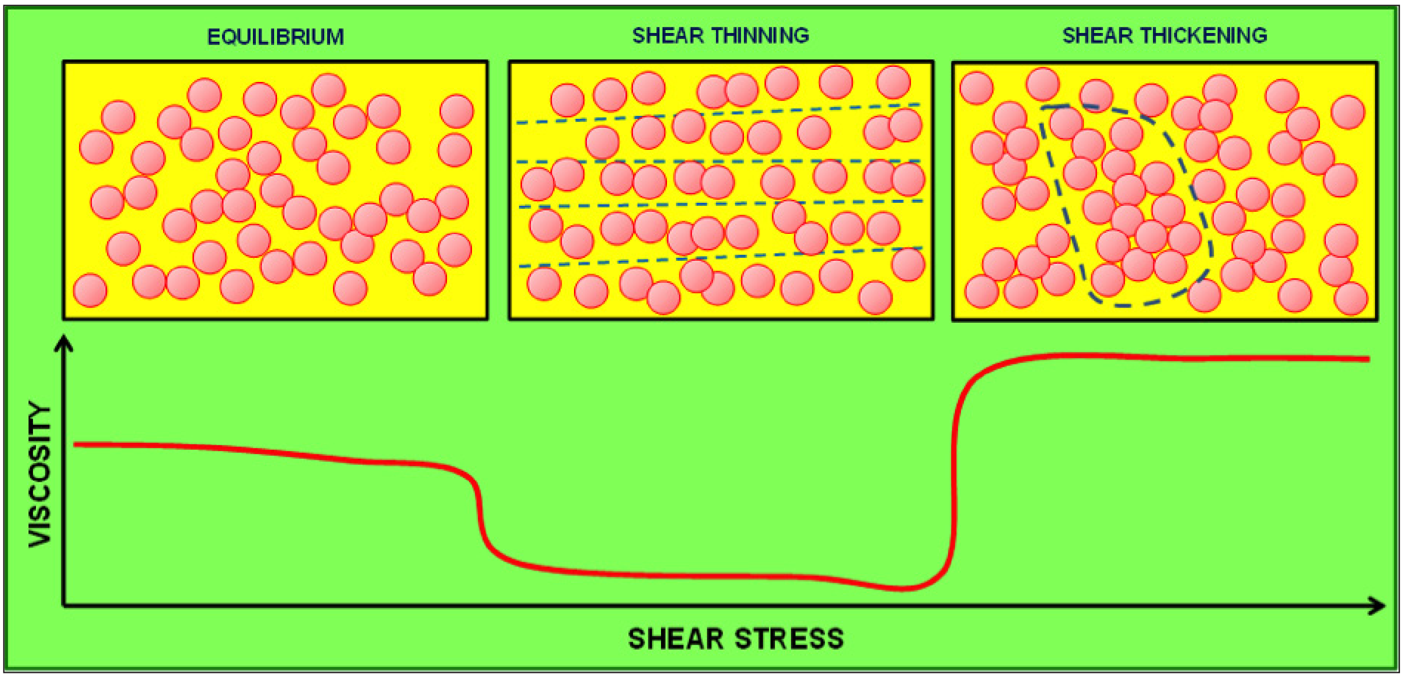
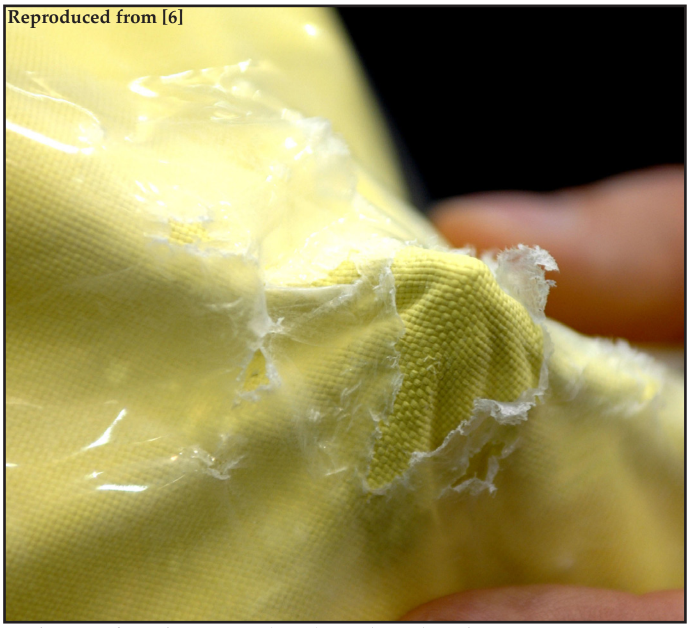


Figure 1 - As shear stress on a shear-thickening fluid increases, the ability of the fluid to flow initially increases - shear thinning because of semi-organised movement of colloids (layers separated with dashed lines) - and then dramatically drops off because the colloids combine into thick clusters - the process known as shear-thickening. One such cluster has been encircled [5]. Diagram by Rok Nezic.

© 2011, The Triple Helix, Inc. All rights reserved.



Resistance of STF-impregnated Kevlar under stab testing.

force to flow easily due to random collisions between the particles. This effect of decreased viscosity for small external stress is known as "shear thinning". However, if the shear force applied is large enough, something counterintuitive and non-Newtonian happens: the suspension is transformed into a solid-like state. Shear (or shear stress), which causes the unconventional behaviour of such substances, is actually just the horizontal component of the stress applied on surface of liquids. The vertical component of such stress is the more familiar pressure.

> **"As research continues, we can expect to discover new fascinating properties of materials around us."**

George Batchelor, former Professor of Applied Mathematics at University of Cambridge, published a number of articles in the 1970s that laid the groundwork for the science of shear-thickening fluids [4]. Essentially, he highlighted that unlike a liquid, in which the comprising molecules flow through vacuum, particles in a colloidal suspension must displace an incompressible liquid any time they move, thus affecting all the surrounding particles. In other words, the molecules in liquids such as hexane do not have to push anything out of the way to move. In contrast, as a colloid moves in a suspension, it has to force some of the suspending liquid aside, which has to move somewhere else; it collides with other colloid particles, which displace more liquid, and so forth. This is the main reason why one has to squeeze a shear-thickening fluid to decrease its viscosity at first, and it helps explain why a sudden, strong stress solidifies the entire mixture—at least for as long as the force is applied. Small stress gets all the particles flowing in rather orderly lines, allowing the suspending liquid, and thus the whole shear-thickening fluid, to flow with little resistance. When a very intense shear stress is applied to a STF, the particles form temporary clusters, as they suddenly squeeze out the liquid separating them. These give the suspension its solid properties. Changes in microstructure and viscosity of a shear-thickening fluid as it undergoes increasing shear stress are shown in Figure 1.

The rapid solidification is exactly what makes the STFs interesting for new prototypes of body armour. By taking just four layers of Kevlar (instead of the twenty to forty currently in use [2]) and impregnating them with a STF, an armour is produced that easily flexes as a soldier moves, but hardens the instant a bullet makes contact. The shear-thickening fluid seeps in between the fibres that make up the Kevlar which causes the entire STF-impregnated fabric to exhibit the fluid's unconventional behaviour. The fluid dynamics involved in the behaviour of shear-thickening fluids are still not very well understood, but it is hypothesised that as an incoming projectile exerts its large force, the shear-thickening fluid clusters around the threads of the Kevlar and prevents them from moving or deforming in the vicinity of the projectile [2]. When the whole structure becomes rigid, the Kevlar absorbs the energy from the impact.

By impregnating four layers of Kevlar with a shear-thickening fluid, one can produce "soft body armour" four times more flexible, but just as strong as current varieties of Kevlar [2]. The downside of this flexibility is that STF-impregnated fabrics do not enhance protection against slow impacts, which can also be harmful. Some studies, however, suggest that even in low-velocity environment, pointed objects such as knifepoints and spikes produce enough stress for STF to improve protection at least partially, because such objects have very small impact area [5].

This branch of defensive technology research has arisen from development of theories of non-Newtonian fluid dynamics and has become one of the supporting pillars of further research in this field at the same time. As the research continues, we can expect to discover and explain new fascinating properties of materials around us. They could help to improve not only defensive technologies, but also our daily lives, as understanding of STF properties of wall paint and concrete already does and as the development of body armour promises to do for such different fields as sports and emergency services [4]. The soft body armour is indeed not limited to the realm of science fiction any more: it has the capabilities to reduce the limb injuries and save lives, while retaining light weight and flexibility. We have come a long way from medieval plate armour. ■

Rok Nezic is a first year student at Homerton College studying Natural Sciences.

References

1. M1917 Steel Helmets. Global Security.org [Online]. Available at: http://www.globalsecurity.org/military/systems/ground/m1917-helmet.htm [cited 2010 Nov 6].
2. Wetzel ED, Wagner NJ. Advanced Body Armor Utilizing Shear-thickening Fluids. Proceeds from the 23rd Army Science Conference. 3 December 2002.
3. Crane, David. [Online]. Baghdad: Improvised Rocket-Assisted Munitions (IRAMs) Arrays Can Kill over Walls. Defense Review. 2008. [cited 6 Nov 2010] Available at: http://www.defensereview.com/baghdad-improvised-rocket-assisted-munitions-irams-arrays-can-kill-over-walls/
4. Wagner NJ, Brady JF. Shear-thickening in colloidal dispersions. Physics Today. Oct 2009. 62(10): 27-32.
5. Y.S. Lee, E.D. Wetzel, and N.J. Wagner. The ballistic impact characteristics of Kevlar woven fabrics impregnated with a colloidal shear thickening fluid. J. Mat. Sci. v38 n13 p2825-2833. 2003.
6. PD, US Army. Available from: http://www4.army.mil/OCPA/uploads/large/techliqarmor42004-12-07.jpg

© 2011, The Triple Helix, Inc. All rights reserved.