DIAMOND AGE

The coming armor renaissance

Body armor today is increasingly seen as too burdensome; too heavy for combat. A recent report featured on military.com[1] summed up the situation:

"'Body armor provides increasingly advanced protection, but at a cost in soldier performance," according to '*The Soldier's Heavy Load*,' part of the '*Super Soldiers*' series of reports that Army Research Laboratory commissioned CNAS to conduct looking at soldier survivability.

"Increased soldier load not only slows movement and increases fatigue, but also has been experimentally demonstrated to decrease situational awareness and shooting response times," the report added.

The document draws on past reports that have estimated soldiers routinely carried an average of 119 pounds apiece in Iraq and Afghanistan. As a result, one-third of medical evacuations from the battlefield between 2004 to 2007 were due to spinal, connective tissue, or musculoskeletal injuries – twice as many injuries as were sustained from combat.

A less recent but still very relevant British Army Review report[2] adds:

"The real problem with soldier load is not leg and back injuries but the tactical impact. Our infantry find it almost impossible to close with the enemy because the bad guys are twice as mobile. A straw poll of three multitour companies found only two platoons that had successfully closed with an ambushing enemy.

We're getting to a point where we are losing as many men making mistakes because they are exhausted from carrying armour (and the things that go with it) than are saved by it."

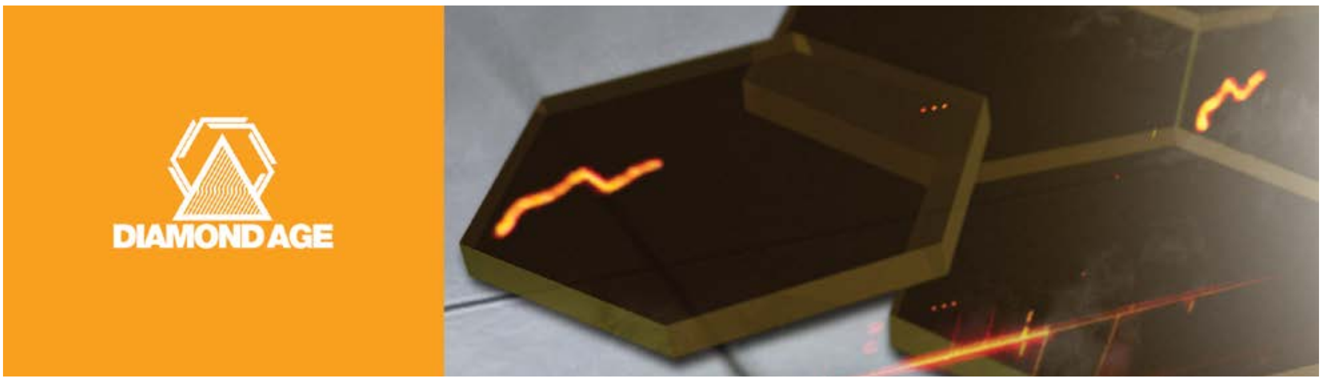
Clearly, improvements must be made. And, surely, they can be made. To understand how, we must first acquaint ourselves with how armor plates are constructed:

Hard armor plates are typically made of a hard but brittle ceramic material bonded to a tough thermoplastic fiber composite. The plates that are standard-issue in most modern militaries are comprised of boron carbide, silicon carbide, or alumina ceramic, over a thick backing layer made of ultra high molecular weight polyethylene fiber-resin laminates (UHMWPE).

When impacted by a hard-cored projectile, the ceramic portion of that typical armor plate will be pulverized around the impact zone – but it will also fracture and decelerate the projectile. The backing layer, which is tough and ductile, subsequently catches all of the ceramic and projectile fragments, and absorbs whatever residual kinetic energy remains via plastic deformation.

Body armor backing layers have evolved at a rapid clip over the past 55 years. They were first made of heavy fiberglass-resin laminates, which were quickly supplanted by aramid laminates, then those were supplanted about 20 years ago by laminates made from early grades of UHMWPE, and now those early grades have evolved into the extremely high-quality UHMWPE laminates currently in use - featuring materials such as Dymeema® HB-212, Teijin Endumax® XF-33, and Spectra Shield® 5241.

Ceramic armor materials, in contrast, have not evolved at all. The current state of the art – the monolithic, multi-curved boron carbide armor ceramic tile – was developed by scientists at the US Army Natick Research and Development Laboratories and Picatinny Arsenal in 1965. If there has been any innovation since, it has been to manufacturing processes; these innovations have brought boron carbide



MATERIAL PROPERTIES

	Boron carbide	Polycrystalline Diamond
Process	Sintered	HPHT
Density	2.5 gm/cc	3.4 gm/cc
Hardness	2400-2700 HV1	5500-7500 HV1
Fracture toughness	2.5 MPa · $m^{1/2}$	8 MPa · $m^{1/2}$
Flexural strength (@ RT)	415 MPa	1044 MPa
Compressive strength	3100 MPa	4200 MPa
Poisson's ratio	0.17	0.086

tile production costs down and have facilitated high-volume production, but, pointedly, none of them have improved performance. (And, indeed, in many cases these innovations have actually reduced performance – e.g. in reaction-bonded boron carbide – RBB4C – that is softer and heavier than the 1965 product.)

In fairness, boron carbide is a fantastic armor material. With its combination of low density (2.52 gm/cc) and excellent hardness, it is a difficult material to improve upon. But it's far from perfect – it has numerous known shortcomings, including low toughness and poor shock tolerance – and it's inferior to a number of known materials. Most of these superior materials are too expensive or difficult to produce; beryllium carbide, for instance, will never be a practical armor material. But one of these superior materials is bulk diamond – and Diamond Age has now pioneered methods to produce bulk diamond tiles in sufficient size, at sufficient scale, for armor applications. Boron carbide has now, at long last, been superseded.

Diamond-faced armor plates from Diamond Age address every shortcoming associated with ceramic armor:

Problem 1: The ceramic component is fragile. For this reason, ceramic armor plates need to be handled with excessive care, need regular inspections, and need replacement after a few years in the field.

Bulk diamond tiles have a fracture toughness 3-4x higher than any known armor ceramic. This means, in practice, that they are generally damage tolerant and resistant to gross fracture.

Problem 2: Ceramic armor is far too thick. The typical standalone ceramic body armor plate is roughly 25mm thick; of which the ceramic layer is 4-9mm, the UHMWPE backing layer is 10-13mm, and there's also usually a foam layer of 2-4mm to protect the ceramic strike-face.

All diamond plate prototypes from Diamond Age are under 14mm thick. Plates under 5mm in total thickness are feasible in the near term.

Problem 3: Boron carbide is subject to extreme supply chain risk. The vast majority of boron carbide plates manufactured in the USA and Europe are produced from Chinese raw materials; there's no US domestic boron carbide production infrastructure.

Bulk diamond tiles are produced from raw carbon, a cheap and abundant raw material, and require no exotic sintering aids or additives.

Problem 4: Following a single ballistic impact, all ceramic armor plates will be fractured along several lines, and utterly shattered around the impact zone – and they will perform inconsistently, at best, thereafter.

Bulk diamond tiles are remarkably fracture resistant, and plates made from them exhibit extremely good multi-hit performance. In one test, a small 5x6" panel withstood five M855 impacts at >900 m/s.

Problem 5: Ceramic armor plates, as a class, are simply too heavy. The very lightest commercially-available ceramic armor plate to stop the M855 at the time of this writing, the HESCO BI-3810, weighs 1.9kg (~4.1 pounds) in a size M SAPI. (It is, moreover, 25mm thick.)

All diamond plate prototypes from Diamond Age are under 1.15kg, and the weight target for Size M SAPI-cut plate is 1kg (2.2 pounds). At this weight, they stop M855 at muzzle velocity.

The new, strongly patented diamond plate technology from Diamond Age is, in short, a revolutionary advance in body armor technology. It enables armor plates which are roughly half as heavy and half as thick as the current best, but which perform just as well in all respects, and which are obviously superior in several key respects such as toughness and thickness. The gradual implementation of these diamond armor plates over the coming years will therefore have major operational impact: Soldiers shall not need to eschew their armor on missions where maneuverability and dismounted mobility are called for. Soldiers will suffer fewer stress, repetitive strain, and heat-fatigue injuries. ***Ultimately, soldiers will be more effective in the field***. ■

1. https://www.businessinsider.com/army-body-armor-adds-weight-to-soldiers-and-may-be-making-jobs-harder-2018-9
2. https://www.wapentakes.com/wp-content/uploads/2016/11/donkeys.pdf