Ballistic Armor Glossary

Common Terms, Threats, and Materials.

Adiabatic shear banding

Cascading failure mode in metal alloys, characterized by narrow bands of highly sheared and weakened material around the site of impact. Essentially a metallurgical effect where an alloy cannot dissipate the heat generated by a violent impact or high-speed machining, and thermal softening outpaces strain hardening in thin bands of material around the site of impact or stress. Micro-cracks nucleate from those thin bands, meet, and initiate gross material failure. In armor, adiabatic shear can dramatically reduce performance, as it generally leads to circular plugs which are ejected from the armor plate around the site of impact — a phenomenon called "adiabatic shear plugging." This is most common in titanium and its alloys, but can also be observed in high-strength martensitic steel alloys. In projectiles, however, adiabatic shear improves performance because it leads to "self-sharpening" behavior — instead of mushrooming, the nose of the projectile is sheared-off and seems to erode, improving through-target sectional density. "Self-sharpening" is most pronounced in depleted uranium AP projectiles, and accounts for their roughly 10% performance advantage over projectiles made from similarly dense tungsten heavy alloys.

Advanced Combat Helmet

"ACH." Combat helmet fielded by the US Army in 2002. Designed as a complete replacement for the PASGT helmet, and wholly derived from the MICH in both form and construction. For technical details, see: MICH.

Air-gap

A vacant space or gap sandwiched between the functional elements of an armor system. See entry for spaced armor. Air-gaps are commonly employed in vehicular armor system designs, particularly where the elements are metallic. As a general rule, air-gaps are deleterious in ceramic armor systems and body armor plates.

ALON

Trade-name for optically transparent aluminum oxynitride ceramic from the Surmet Corporation — which has gradually become a generic term, in that all aluminum oxynitride ceramics are now referred to as "ALON." Aluminum oxynitride was discovered when it was found that the addition of nitrogen to alumina resulted in a new spinel-like (cubic) phase. Like most oxynitrides, ALON is not a compound in its own right, but is best understood as a solution of nitrogen or aluminum nitride in Al2O3. ALON is the most common and widely-employed polycrystalline transparent armor material — amorphous glasses and polymers, and semi-amorphous glass ceramics, are, however, much more common.

Density: 3.69 gm/cc
Hardness (Vickers): 1900 HV
Fracture toughness: 2 – 2.9 MPa · m^1/2
Melting point: ~2150°C
Compressive strength: 2700 MPa

Alumina, Aluminum Oxide, Al2O3

Common ceramic material and natural mineral consisting of aluminum in its highest oxidation state. Highly pure aluminum oxide is produced in tremendous bulk quantities, well over 100M tons per year, as it is an intermediary in the production of aluminum and its alloys. In its own right, it is the most popular industrial and armor ceramic by a very wide margin. In armor, its popularity can be attributed to its low raw material cost, ready availability, reasonably good performance, thoroughly well-understood nature, and ease of manufacture. Virtually all land vehicles that utilize ceramic armor employ aluminum oxide. In body armor, it is very common in low-end plates for police and civilian use, but is growing increasingly obsolete in military-issue plates.

Density: 3.98 gm/cc
Hardness (Vickers): 1200-1600 HV
Fracture toughness: 3 – 4.5 MPa · m^1/2
Melting point: 2072°C
Compressive strength: >2000MPa

Aluminum armor

Armor plate made primarily of an aluminum alloy. Relative to other metallic armor options, aluminum alloys are relatively inexpensive, highly corrosion-resistant, and can exhibit great specific strength — but their hardness is fairly poor. Aluminum is not currently used to any substantial extent in body armor, but it is second only to steel in vehicular and naval armor applications. The most common alloy used in armor is 5083, which, in the H-131 temper, has been used in systems such as the M1113, the M109, and the USMC Amphibious Assault Vehicle, in accordance with specification MIL-DTL-46027J. 7XXX-series aluminum alloys are much stronger than 5083-H131, and exhibit better ballistic performance on a weight basis, but have an increased susceptibility to stress-corrosion cracking, and are much more difficult to weld, so have not seen widespread use in armored vehicles. Though aluminum is not used in body armor at present, some of the first ceramic composite armor plate prototypes consisted of ceramic tiles bonded to an aluminum alloy backer. E-glass composites quickly replaced aluminum in that role.

Amorphization

Decomposition of a material's crystalline and molecular structure. Amorphization is a common failure mode in boron carbide, which is dynamically unstable at very high pressures. That is to say, when boron carbide is subjected to extreme pressures at high strain rates — typically when it is struck with a high-velocity tungsten carbide or tungsten heavy alloy AP projectile — its molecular structure breaks down and bands of amorphous, glassy boron carbide form around the impact site. This amorphous boron carbide is substantially weaker and more brittle than well-ordered crystalline boron carbide, so the process of amorphization has a profoundly negative effect on ballistic performance. Amorphization is similar in some respects to adiabatic shear banding.

Amorphous solid

Solid material that, like a liquid, lacks an ordered crystalline structure. Glass is an amorphous mixture of oxides that, if crystalline, would be ceramic materials. Many polymers, e.g. polycarbonate, are amorphous. Amorphous metals — also known as bulk metallic glasses — are noteworthy for their strength and hardness, but, much like ceramics and glasses, are brittle. Generally, amorphous solids are prepared by taking a molten material and forcing it to solidify very rapidly, so that the molecules do not have the time to arrange themselves into a crystalline lattice.

Angle of obliquity

Angle at which a projectile strikes a target or armor plate. In this context, 90° and 0° are equivalent — they both describe a projectile that strikes its target dead-on.

Anisotropic

Having different physical and mechanical properties in various directions. E.g., an anisotropic block of material may be strong if you strike one of its surfaces, but significantly weaker if you strike a different surface. All fiber and fiber-composite materials are anisotropic, as are all single-crystal materials such as sapphire glass. Many metal alloys are also anisotropic to some extent, particularly those with ordered microstructures, e.g. pearlitic steels. Amorphous materials and glasses are, by definition, isotropic — that is, not anisotropic. Ceramics are also typically isotropic, though there are exceptions.

AP, Armor piercing

Full metal jacket bullet with a high sectional density and a hardened steel, tungsten heavy alloy, depleted uranium, or tungsten carbide-cobalt cermet core, designed specifically to penetrate armor and hard barriers.

API, Armor piercing incendiary

Full metal jacket bullet with an AP core and an incendiary chemical mixture sandwiched between the AP core and the bullet jacket. The incendiary mixture, which initiates a small explosion when the bullet strikes an object at high velocity, is usually comprised of magnesium, aluminum, and barium nitrate. The most common small-arms API rounds are Soviet bloc relics such as the 7.62x39mm API-BZ and the 7.62x54Rmm B-32 API. (In the API-BZ, the incendiary mixture weighs just 2 grains, or about an eighth of a gram. In the B-32 API, the mixture weighs 4 grains.) The reason for this has much to do with Soviet design philosophies, such as the apocryphal "*quantity has a quality all its own*," and API small-arms rounds from 7.62mm through 14.5mm in diameter were produced in truly vast quantities in the Soviet bloc as multi-purpose projectiles. Their soft-target performance could be markedly superior to regular AP rounds, but their anti-armor performance appears to be, generally, either equivalent or very slightly inferior to regular AP rounds. At an equivalent velocity, against ceramic composite armor, the .30-06 APM2 performs roughly 5% better than the 7.62mm B-32 API, despite the fact that the B-32 API projectile has a slightly more massive hardened steel penetrator. (83 grains for the B-32, 81 grains for the APM2.) Against steel armor, the picture is reversed, and the B-32 API performs slightly better than the APM2.

APM2

Used to refer to the 7.62×63 millimeter (.30-06) M2 AP bullet with a specified mass of 10.8 grams (166 grains) ±5 percent. At a typical velocity of 878 ± 9.1 meters per second (2880±30 feet per second), the APM2 is among the most common test projectiles for ceramic body armor, and is the round used to certify NIJ Level IV/RF3 armor. The APM2 has a long martensitic steel penetrator with a high sectional density. The hardness of the penetrator is inconsistent; some are as soft as 57 Rockwell C, others as hard as 65 Rockwell C. The penetrator's mass is 81 grains, or 5.25 grams, and it was made of 1070 tool steel. Was. The APM2 is no longer in production, and the rounds used in armor testing are from old US military stockpiles.

Confusingly, there is a .50 caliber AP projectile also called the APM2, but it is somewhat less common overall, and is much less common in armor testing.

Appliqué

Armor system designed to be placed on top of a separate, discrete armor system. An external "up-armor" kit for an armored military vehicle is appliqué armor; a reinforcing ceramic or UHMWPE plate that attaches to the surface of a combat helmet is appliqué armor; strictly speaking, even an ICW body armor plate is appliqué armor. This is a very old concept, and has seen wide use from Antiquity through early modern times; Emperor Charles V, for instance, had eight appliqué plates built for a single helmet.

Aramid

Strong fiber derived from highly aligned aromatic benzene rings connected with amide (−CO−NH−) bonds. Meta-aramid and para-aramid differ in the location of their amide bonds. In meta-aramid, the bonds are in a zig-zag pattern, which results in a more flexible but weaker fiber; in para-aramid, the bonds are oriented along the long direction of the aramid fiber, which results in a stronger and stiffer fiber. As para-aramid is tougher, lighter, easier to work with, and more flexible than S-glass, para-aramid has seen extensive use in body armor systems from the early 1970s onwards. Para-aramid is unique among fibrous ballistic materials in that it often isn't sold as a resin-composite, but is supplied in plain woven sheets of fabric. Due to recent advances in UHMWPE engineering, para-aramid is growing increasingly obsolete in body armor systems, but it is still the fibrous armor material of choice where good thermal stability is a requirement. Technora and the Russian aramids are chemically-modified para-aramid derivatives. Vectran is a strong fiber closely related to para-aramid.

Areal Density

Measure of mass per unit area, generally used in either kilograms per square meter (kg/m2) or pounds per square foot (psf). Because armor plates come in various sizes, areal density is a popular way to compare different system configurations. A 10×12" rectangular armor plate that weighs 5 pounds has an areal density of 6 pounds per square foot.

This measure usually *does not* take curvature into consideration, so a flat armor plate will often seem to have a lower areal density than a curved one, and a plate with a very slight curvature will seem to have a lower areal density than one that is curved more severely.

Atom percent (at%)

The percentage of the number of atoms of a particular element relative to the total number of atoms of all elements within a compound or alloy. For instance, tungsten carbide, WC, contains an equal ratio of carbon and tungsten atoms. (50 at% C.) But because the tungsten atom is so much larger and heavier than the carbon atom, it's nearly 94% tungsten by weight.

Auxetic

Material that possesses a negative Poisson's ratio — i.e., a material that gets thicker when stretched and thinner when compressed. This is in stark contrast to most materials, which get thinner when stretched and thicker when compressed. In theory, perfectly auxetic materials are infinitely ductile, and can absorb tremendous amounts of energy without failure. Auxetic materials are, therefore, of considerable interest in armor applications. α-cristobalite, a silica polymorph, is naturally auxetic. However, most auxetic materials are more properly termed auxetic *structures*: They are not naturally auxetic on a molecular level, but are artificially structured or patterned in such a way so that their micro- or macro-geometry imparts an auxetic effect.

Backer

Ductile support material behind the strike-face in ceramic composite armor. Thin ceramic plates are brittle and highly susceptible to tensile and shear failure, so they must have a backer of some sort if they are to be useful in armor systems. In body armor systems, S-glass, e-glass, aramid, and UHMWPE are the materials used for this purpose, with UHMWPE now dominant in military body armor systems. Metals are used in vehicular armor systems.

Backface deformation

A measure of residual blunt trauma following the impact of a projectile onto a body armor plate.

Armor plates are designed to absorb kinetic energy, and one of the ways they do this is via plastic deformation — in other words, they convert the kinetic energy of the projectile into heat, friction, and motion. This means that, upon impact, armor plates often bulge inwards and in some cases are highly deformed.

In body armor testing, an armor plate or panel is placed over a clay surface and is struck by a test projectile at a prescribed velocity and angle of impact. Assuming the projectile is stopped, backface deformation is measured by recording the depth of the indentation left in the clay. Castable soft materials such as soap and wax are sometimes used instead of clay. Clay can be inconsistent and highly sensitive to temperature, so the search for a more consistent replacement material is ongoing.

Bainite

Steel microstructure that, like martensite and pearlite, is formed when steel is heated to form austenite and then cooled. To produce martensite, the steel must be quenched quickly; to produce bainite, the steel is cooled at a moderate rate; to produce pearlite, the steel must be cooled slowly. Bainite, unlike martensite but much like pearlite, is a structured compound of ferrite and the iron carbide cementite — but its structure is needle-like and resembles martensite on a visual level. Bainite has properties that are broadly intermediate between pearlite and martensite — it’s harder than even the best grades of pearlite, but not quite as tough or as strong; it’s stronger and tougher than most martensitic steels, but can’t attain the same peak hardness values. On the whole, bainitic steels show great promise in armor applications.

Ball

In the 20th century, “ball round” would refer to a pointed full metal jacket bullet with a mild steel or lead core. Yet the new 5.56x45mm M855A1 and 7.62x51mm M80A1 projectiles are officially referred to as “ball,” despite the fact that they have hardened steel penetrators and were designed, at least in part, to penetrate armor and hard barriers as well as exhibit good performance against soft targets. The M80A1 and M855A1 aren’t quite FMJ, either. So the term “ball round” may have quietly evolved to encompass a new definition: “Ammunition, general purpose, not specifically intended as armor piercing ammunition.”

Ballistics

Field of mechanics and engineering concerned with the dynamics of projectiles. It is generally split into four distinct disciplines. (1) Internal ballistics, which is concerned with what happens inside the gun after the firing pin hits the primer. (2) External ballistics, which has to do with the bullet in flight after it leaves the barrel — trajectory, spin, yaw, wind effects, angular deviation, etc. (3) Terminal ballistics, which is the study of projectile-target interactions. And (4) forensic ballistics, a top-down science which, generally, aims to re-create individual ballistic events in their entirety. Internal ballistics is the province of gun designers. External ballistics is of obvious importance to shooters and artillery gunners, and was once of great interest to governments and mathematicians — such luminaries as Leonhard Euler, Benjamin Robins, and Daniel Bernoulli contributed greatly to the field of external ballistics. Terminal ballistics, broadly speaking, encompasses the sciences of armor and of projectile design. Forensic ballistics is largely a police discipline, and, to a lesser extent, is also of interest to those in the medical field.

Ballistic fabric

Fabric woven from high-strength fibers that were twisted to form yarn. The optimum twist angle is roughly 7°. The most common weave patterns are plain and basket weaves. Aramid and Zylon fabrics can be used neat, but most ballistic fabrics are used in the manufacture of prepregs and fiber composites.

Ballistic nylon

High-denier, basket-woven nylon fabric. The original ballistic nylon specification called for 1050 denier nylon, in a 2×2 basket weave, in an exceptionally heavy 423 grams per square meter fabric. (18 ounces per square yard.) When layered, this heavy nylon fabric provided some protection against fragments and flak. Very early soft armor panels for police use were made from ballistic nylon, but these were invariably very thick and heavy, and generally provided protection only to the NIJ’s depreciated Level I or Level IIa standards.

Ballistic penetration mechanism

Term to describe the ways projectiles might penetrate armor. In metal armor, the typical penetration mechanisms include ductile perforation (hole enlargement by radial flow), plugging, petaling, brittle fracture, and spall fracture. In fabric composites, fiber breakage, yarn pull-out, and, to a lesser and limited extent, melting are the typical penetration mechanisms. In ceramic materials, brittle fracture dominates — typically, in ceramic-composite systems, with the formation of the characteristic fracture conoid.

Ballistic shield

Hard armor ballistic barrier. The most common type, which more closely fits the classical definition of the word "shield," is hand-held or supported by its user's body. A rather less common type is too large and heavy to be used in such a manner, and is supported by a wheeled trolley. Ballistic shields are similar to hard armor plates in their construction. Unlike body armor plates, however, they are frequently functionalized with transparent armor windows, lights, speakers, etc.

Ballistic limit

Minimum velocity at which a particular threat is expected to consistently and reliably penetrate a particular armor system. Typically assigned via statistical methods subsequent to V50 testing. Closely related to, and indeed the inverse of, the V0.

Beryllium

Uncommon light metal with a higher specific stiffness than any other metal or alloy, good strength, poor ductility, and a very low density of 1.85 gm/cc. Certain lightweight beryllium-based ceramics — particularly beryllium oxide, BeO, and the beryllium borides, Be2B and Be4B — have been investigated for use as armor ceramics, and all of them perform extremely well. Be2B is, in fact, the best-performing ceramic material on record. Beryllium is, however, highly toxic. If beryllium-containing dust is inhaled, it can trigger the development of a chronic lung disease called beryllosis, which is always severe and proves fatal in 5-38% of cases. Beryllium and its compounds are also potent carcinogens. In large part because of the extreme precautions that need to be taken in its handling and processing, beryllium is an unavoidably expensive material with very few industrial uses, and a dwindling number of military uses. So, despite good performance, it is not used in any articles of armor at this time.

BFD

See: Backface deformation.

Boride

Ceramic material where a metallic or metalloid element is combined with boron. These are generally uncommon materials. Titanium diboride is the classical example of this class, and is the only boride that has seen widespread use in armor, for certain values of "widespread." Calcium hexaboride has metallurgical applications, cerium hexaboride and lanthanum hexaboride are used in cathodes, and magnesium diboride has come to public attention as a relatively high-temperature superconductor. All other borides are, by and large, scientific curiosities with no industrial or military uses.

Boron Carbide

Synthetic ceramic carbide derived from boron and carbon with a broad potential range of compositions — anywhere from B4.3C to roughly B14C. Boron carbide is a black-gray ceramic material which combines exceptionally good hardness with a very low density of just 2.5 gm/cc, so it has seen relatively wide use in very high-end and military-issue armor plates. It is susceptible to shear amorphization at high impact pressures. Nevertheless, against most threats boron carbide is the best-performing readily available ceramic material, and there are strong indications that the shear amorphization problem can be suppressed via doping strategies that are as inexpensive as they are easy to implement.

Density: 2.51 gm/cc
Hardness (Vickers): 2400-3100 HV1
Fracture toughness: 2.5 – 4 MPa · m^1/2
Compressive strength: ~3000 MPa
Melting point: 2427°C

Boron Nitride

Synthetic ceramic nitride derived from boron and nitrogen with only one composition, BN, but two common allotropes — that is, structural configurations — that couldn't be more different. There is, first, a graphite-like hexagonal form, called hexagonal boron nitride or hBN, of low density (2.1 gm/cc) and extremely low hardness and strength. This is the stable form at ambient pressure, and, like graphite, is used in heating elements, furnaces, crucibles, and other metallurgical implements. The other form, the high-pressure form which is only metastable at ambient pressure, is diamond-like and cubic. Called cBN, it is of of high density (3.45 gm/cc), and its hardness and strength are second only to diamond. cBN — which is extremely expensive, difficult to make, and anywhere from 50-100% harder than boron carbide — has been the subject of several ballistic experiments in recent years, with the surprising result that it has *no performance advantage over boron carbide when the two are compared at an equal-weight basis*. Thus both forms of boron nitride are quite unsuitable for use in armor.

Boron Suboxide

Synthetic ceramic material derived from boron and oxygen with the composition B_6O. Structurally analogous to boron carbide, with carbon atoms swapped out for oxygen atoms. Emphatically not a classical oxide ceramic, and possibly better termed "oxygen boride," for it has much more in common with the boride ceramics than it does with any of the oxides. In any case — and likely *because* it is not a classical oxide — boron suboxide is the hardest known oxygen compound. It has been investigated for use as an armor ceramic with promising preliminary results; it may be effectively immune to the amorphization problem that affects boron carbide, and may also exhibit some ductility at extremely high strain rates. B_6O is, however, wholly synthetic, it is very expensive to synthesize as a powder raw material, and it is next to impossible to produce dense ceramic parts from that powder via standard industrial sintering and hot-pressing techniques. (That last point is something it has in common with another boride, TiB_2, though B_6O's sintering problems are if anything more severe.) For these reasons, armor systems with a B_6O component have never been developed, and its future as an armor material is in doubt.

Density: 2.56 gm/cc
Hardness (Vickers): 2800-3200 HV1
Fracture toughness: 2.5 – 4 MPa · m^1/2
Compressive strength: ~2000-3000 MPa
Melting point: 2000°C

Brittle fracture

Ballistic penetration mechanism defined as the condition of little-to-no plastic deformation during the propagation of cracks upon impact. The projectile then penetrates through shattered or comminuted material. This is the default penetration mechanism in ceramics, due to their lack of ductility, and is common in very hard and poorly ductile metal alloys, such as tool steels.

BTD, Ballistic Transient Deformation

See: Backface deformation.

Bulletproof Glass, Ballistic Glass

Transparent armor, usually used in structure or vehicle windows, comprised of sheets of laminated glass bonded with a transparent elastomeric adhesive. The glass is often of a standard commercial grade, such as plain soda-lime glass. The adhesive is usually polyurethane. There may be layers of acrylic (PMMA) or polycarbonate between the glass plates, to improve ballistic performance and durability. Ballistic glass is usually over .75" in total thickness, and is frequently as thick as 3.5" — which makes it very heavy. Because bulletproof glass has obvious shortcomings, there is a great deal of active research into improved transparent armor materials, such as ALON and spinel.

Carbide

Ceramic material where a metal or metalloid is combined with carbon. Silicon carbide is the classical example of this class, and is the most common and industrially useful carbide. Boron carbide is another carbide, sometimes used in high-end body armor or aerospace armor. Other relevant carbides include tungsten carbide and titanium carbide — both of which see little use in armor, but are very common industrial tool-and-die "hardmetals," and a tungsten carbide cermet features prominently in AP bullet cores. Carbides naturally form in certain steel alloys, which typically improves the hardness but reduces the toughness of those alloys.

Carbon fiber

Fibrous material utilized primarily in the manufacture of composite panels for structural applications. Comprised of very fine strands of graphitic (sp2) carbon, and rarely used as a ballistic material on account of its brittleness, relatively high density, and lack of ductility. Its very high strength and stiffness, combined with a truly extreme degree of thermal and chemical resistance, make it useful in certain niche applications in armor, e.g. in structural support layers. There are many different grades of carbon fiber, and there are many different ways to make composites from them, so two different types of carbon fiber composite can have very different mechanical and impact properties.

Carbon nanotube

Hollow tube made of sp2-bonded, graphitic carbon — much like a miniaturized carbon fiber — with a diameter typically measured in nanometers. In theory, yarns and fabrics derived from carbon nanotubes should be extremely strong, but these have not yet materialized. Carbon nanotubes have been investigated as a reinforcing material for metals and ceramics, with very limited success. Some of the trouble is on account of the fact that CNTs are unstable in the presence of elements such as iron, and unstable at the temperatures employed in ceramic and powder metallurgical sintering.

Carborundum

Generic trade-name for synthetic polycrystalline silicon carbide. (As opposed to "moissanite" which is a generic trade-name for synthetic single-crystal silicon carbide.)

Carrier

Fabric garment used to hold hard armor plates or soft armor panels in position. Carriers can be "overt" or "covert."

Overt carriers are designed to be worn over clothing. They are often dyed in camouflage patterns, are made of durable high-denier nylon fabrics that have been specially treated for low IR reflectivity, and are functionalized with PALS webbing and foam padding. High-end overt carriers may also feature load-bearing supports, pouches, cable guides, spacer mesh fabrics for airflow on the body-side, a dedicated pouch for a hydration unit, etc. Standard-issue military carriers, such as the PASGT, IBA, and IOTV, are always overt.

Covert carriers are designed to be worn under clothing. They are generally made of soft and flexible fabrics, are a neutral color, and offer no added functionality.

Ceramic

Material which is inorganic, non-metallic, synthetic, and polycrystalline. Most ceramics are comprised of metallic or metalloid elements bonded to oxygen, carbon, nitrogen, silicon, boron, or phosphorous, in descending order of abundance and industrial importance. Metals bonded to other metals are in many respects similar to ceramics, but are more appropriately termed intermetallics. As noted, the most common ceramic types are the oxide ceramics — which consist of metallic or metalloid elements combined with oxygen and are exemplified by aluminum oxide — and the carbide ceramics — which consist of metallic or metalloid elements combined with carbon, e.g. in silicon carbide. Other types include borides, nitrides, etc. Ceramics in general are noteworthy for their resistance to heat and thermal shock, their high hardness, and their low density. They are not useful as structural materials, however, on account of their brittle nature — that is, their lack of ductility, and their inability to dissipate impact forces via plastic strain.

Ceramic matrix composite (CMC)

Ceramic material reinforced with fibers, whiskers, wires, or nanoparticles. Generally, CMCs exhibit substantially improved fracture toughness values, at a penalty to hardness and compressive strength. The mass fraction of the reinforcing material is typically on the order of 10% or less. Carbon fiber reinforced silicon carbide — C/SiC — is popular as a ceramic armor material in very high-end and demanding vehicular applications, where multi-hit performance is a key requirement. Other ceramics, such as silicon nitride, are frequently reinforced with silicon carbide whiskers for improved fracture toughness. CMCs have many industrial uses, particularly in the automotive and aerospace sectors, and increasingly in the energy sector. Research-grade ceramic-nanotube and ceramic-graphene composites are CMCs.

Cermet

Ceramic material reinforced with a secondary metallic phase, usually as a binder. The metallic phase typically makes up 5-15% of the cermet by weight. Reaction-bonded boron carbide and reaction-bonded silicon carbide are cermets made with silicon. The tungsten carbide penetrators in AP cores like the M993 are cermets; they contain a cobalt metal binder. Titanium carbide cermets, with nickel and molybdenum as the metallic binder phase, have been successfully tested in armor applications, and, high density aside, they exhibit impressive performance characteristics. Cermets made with nickel and cobalt can exhibit improved ductility and tensile strength compared to the unmodified ceramic materials they are derived from — but most cermets, like for instance the reaction bonded grades of silicon carbide and boron carbide so popular in military-issue armor plates, exhibit near-zero ductility and are functionally equivalent to ceramics in this respect.

Cheat ring

Colloquial term. Most ceramic composite armor plates have a ring of foam around the rim, so as to prevent the ceramic strike-face from fracturing if the plate is dropped on a corner or on its side. In most plates, this form ring is thin and shallow. But in some other plates, typically Asian imports, the foam ring can be *very* wide and deep, so, for instance, that a plate that *measures* 10" across and 12" high only offers 8×10" of protective coverage. The extra-deep and extra-wide foam ring, in this case, is called a cheat ring. The cheat ring "helps" manufacturers in two ways: First, it makes plates much cheaper to manufacture. Second, it makes them look better on spec-sheets, as they'll almost invariably exhibit a very light weight for the level of protection they offer.

Chobham Armour

Tank armor system where thick ceramic composite armor tiles are sandwiched between two layers of conventional, and structural, RHA. Some modern tanks encapsulate the ceramic composite bricks in depleted uranium before sandwiching it between RHA.

Complex carbide

Carbide which contains a mixture of metallic elements bonded to carbon. e.g., (Fe,Ni)23C6, or (Fe,Mo,W,Cr,V)6C. Complex carbide precipitates are common in steel alloys, particularly in the sort of high-carbon tool steels that are frequently used in AP projectiles.

Composite

Any material comprised of two or more chemically different and insoluble constituents. Most fibrous armor materials, like fiberglass and UHMWPE, are composites by definition, as they contain a fiber component and a resin or plastic component. Composites can also be microscopic in scale; the reaction-bonded cermets, and multi-phase ceramics like ZTA and ALON, are also composites.

Composite armor

Armor comprised of two or more different material components. A ceramic strike-face over a fiberglass backer is a composite armor system — and may be referred to as a "ceramic composite armor plate." The term "composite armor" is also, incorrectly, used to refer to armor made wholly of fiber-composite materials, such as UHMWPE.

Composite metal foam

Closed-cell metal foam where hollow metallic spheres are embedded within a solid metal matrix. Distinct from — and much stronger than — regular "metal foams" (see entry for foam) which are open-cell foams that are also known as "metal sponge," and indeed resemble sponges. Various types of composite metal foam have been investigated for use in armor, and are of interest in vehicular armor applications. Their performance characteristics do not translate well to body armor, primarily on account of space-efficacy limitations.

Contact shot

A shot fired with the barrel of the test weapon in contact with the carrier of the vest. Utilized in the DEA, FBI, and SK armor testing protocols. It has been surmised, credibly, that heat transfer from contact shots can sometimes lead to melting failure in soft armor made from UHMWPE.

Copolymer

A polymer that consists of two or more dissimilar repeat units along its molecular chain. A polymer with only one repeat unit is called a homopolymer, and UHMWPE and Zylon fall into this category. Homopolymers can be represented [X]-[X]-[X]-[X]-[X]-[…] — where X is the repeat unit or monomer. Copolymers can form in several configurations. In the random copolymer, repeat units are randomly arranged: [X]-[Y]-[X]-[X]-[X]-[Y]-[Y]-[X]-[…]. In the alternating copolymer, repeat units alternate in a regular order: [X]-[Y]-[X]-[Y]-[X]-[Y]-[…]. Block copolymers are where each monomer is arranged in a long block: [X]-[X]-[X]-[X]-[X]-[Y]-[Y]-[Y]-[Y]-[Y]-[…]. Aramids — including technora and the Russian aramids — are alternating or block copolymers. Nylon is also a copolymer.

Cordura

Trade-name for nylon and nylon-composite fabrics from DuPont. Widely used in body armor carriers, and also used to wrap hard body armor plates.

Corundum

Polycrystalline alumina. By a wide margin the more common natural form, and the dominant form of alumina in armor and industry.

Coupon

A small, flat armor sample made explicitly for ballistic testing purposes. Typically used in materials and systems R&D, especially when testing full-sized armor samples would be impractical for cost or material availability reasons. A typical armor coupon is a square which measures about 100mm (roughly 4") per side, or a disc with a 100mm diameter.

D-Value equation

Mathematical formula commonly used for estimation of the ballistic merit of ceramic materials in armor.

$$D = \frac{0.36(H_V Ec)}{K_{IC}^2} = SBc$$

Where "Hv" is Vickers hardness, "E" is elastic modulus, "c" is sonic velocity, and "KIC" is fracture toughness. Interestingly, fracture toughness is squared, which means that it's the most important parameter in the equation. Even more interestingly, it is in the denominator, which means that the *lower* the fracture toughness, the higher the figure of merit, and therefore the better one might expect a ceramic material's performance to be! Those oddities notwithstanding, the D-Value equation accurately predicts that, against steel-cored threats, boron carbide should perform better than silicon carbide (on a weight basis) which itself should perform better than aluminum oxide. The equation does not accurately predict the performance of ceramics, such as spinel ($MgAl_2O_4$) or titanium diboride, which have unusual mechanical properties and may exhibit some ductility upon impact. Also, and in something of a more serious failure, it does not accurately rank two different ceramics of the same type, which differ in their material properties. Overall, although the D-value equation can be a useful tool, there is no clear relationship between a ceramic material's mechanical properties and its ballistic performance — or, at least, nothing that can be expressed in so concise an equation.

DEA rated

Article of armor that has successfully been tested to the US Drug Enforcement Administration's in-house ballistic specifications. The DEA's soft armor testing protocol is famously stringent, with extensive high-temperature and low-temperature conditioning requirements, contact shot requirements, and fragment-protection requirements (i.e., tests against FSPs,) that are all well beyond what the NIJ's testing specifications call for. The DEA's hard armor test protocol is much the opposite; it neither tests hard armor against heavy-hitting or AP rounds, nor does it test armor that has been conditioned to heat or cold, nor is there a drop test, nor does it even measure backface deformation. Ultimately, successful compliance with the DEA's specification is a mark of exceptional quality in soft armor, but has very little to say for hard armor.

Degree of polymerization

Average number of repeat units per polymer chain molecule. Particularly useful in the characterization of ballistic fibers.

Denier

Arbitrary unit of textile mass-density measurement. 1 denier is the weight of a 9000 meter long (about 5.5 mile long) strand of silk. Silk being exceedingly fine and light, this comes out to roughly one gram, or 1/24 ounce. Coarse fabrics are high-denier — such as 1000 denier nylon, which is comprised of thick and strong fibers — whereas "microfiber" fabrics are, by definition, "sub-denier," or under 1 denier. It is important to note that the denier is *only* a measure of mass-density, and that it does not measure toughness, strength, abrasion-resistance, or any other quality sometimes ascribed to high-denier fabrics.

Depleted uranium

Uranium metal parts or alloys which are depleted of the radioactive isotope 235U. Natural uranium contains roughly 0.72% 235U; depleted uranium contains roughly 0.3%. DU is highly dense at 19 gm/cc, which compares well with tungsten and far exceeds the densities of steel and lead. DU projectiles thus have high sectional density. What's more, DU projectiles exhibit "self-sharpening" behavior — the metal's thermal properties promote adiabatic shear banding around the nose of the penetrator upon impact, so it whittles itself away rather than mushrooming. Finally, DU is naturally pyrophoric; its dust or shavings spontaneously erupt into flame in air, making it naturally incendiary upon ballistic impact. For all of these reasons, DU AP projectiles generally out-perform those made from tungsten alloys, by roughly 10%. DU is, however, controversial, for it is still somewhat radioactive, it persists in the environment, and exposure to it is associated with birth defects and other unfortunate health outcomes. Like tungsten heavy alloys, DU is very rarely, if ever, utilized in small-arms projectiles, but is very common in 30mm and larger rounds and munitions.

Depth of penetration test

Method developed in the 1980s, which was intended to provide a method by which different ceramic materials can be directly compared. A projectile, typically a tungsten heavy alloy long rod with an aspect ratio of 4 or higher, is first fired upon a very thick ("semi-infinite") brick made of steel or polycarbonate. The projectile will never perforate the semi-infinite brick completely, but may penetrate several inches or more into the brick, and the depth of the penetration channel is recorded. This becomes the "reference" depth of penetration. Ceramic tiles are subsequently bonded to identical semi-infinite bricks and the experiment is repeated, to see what effect the ceramic strike-face has on the total depth of penetration compared to the reference value.

Example: A projectile's depth of penetration into a semi-infinite steel block is 100mm. When a 10mm-thick boron carbide ceramic strike-face is fastened onto that block and tested, the depth of penetration into the steel is recorded at 50mm. When a 10mm-thick silicon carbide ceramic strike-face is fastened onto that block, the depth of penetration is recorded at 45mm. Because boron carbide is roughly 20% less dense than silicon carbide, it has just exhibited better performance on a per-weight basis. Silicon carbide, however, has exhibited better performance on a per-thickness basis. What constitutes "better" performance is left to the discretion of the armor engineer; some applications call for low overall mass, whereas others call for high space efficacy. (Body armor is always in the former category!)

Because of the extremely thick and rigid semi-infinite backer, and because the projectiles used in DoP testing are typically tungsten long rods which are qualitatively different from small arms AP threats, results derived from DoP experiments don't necessarily translate to body armor systems engineering. The relevance of the DoP test towards vehicular armor is also hotly debated. In the 90s and 2000s, some attempts were made to standardize the DoP test, but these were ultimately unsuccessful.

Doping

Intentionally introducing an impurity so as to promote the development of a desired characteristic. In ceramic materials, a doped ceramic is essentially the same thing as a metal that has been alloyed. Where armor is concerned, this concept is primarily of interest in boron carbide, where doping with, e.g., metallic silicon at 0.15 to 1.5 at. % seems to improve molecular stability and ballistic performance. (See: amorphization.) At that low concentration, and if properly and uniformly dispersed in the boron carbide matrix, the silicon generally won't form new compounds. Instead, silicon atoms will substitute for carbon at certain key structural points and will suppress the growth of the deleterious B12-C-C-C and B11-C-B-C polytypes, which are nucleation sites for amorphization failure. Doping is also of great importance in semiconductor production, where very specific amounts of dopants are added in tightly controlled processes.

Doron

Laminate hard armor composite material made of compressed fiberglass sheets bound with polyester resin. Doron was the first form of fiber composite armor; the Doron project was initiated in June 1942, and Doron plates were issued to Marines in 1944, in the last stages of the battle for Okinawa. Doron subsequently saw wide use in Korea and Vietnam, primarily with the Navy and USMC, for the Army, at the time, preferred vests made of flexible ballistic nylon. Doron was named after Brig. Gen. Georges F. Doriot, who in 1942 was chief of the Military Planning Division, OQMG, and spearheaded the fiberglass composite armor project. Doron, as a standalone anti-fragmentation armor material, was rendered obsolete with the introduction of

Kevlar in the early 1970s, and this particular "brand" of fiberglass-polyester composite has therefore been out of military service for decades. It is of interest primarily as a historical curiosity.

Drop test

In ceramic composite armor testing, this is when a hard armor plate is dropped on its ceramic surface in a prescribed way, generally a methodical and repeatable way, so as to gauge its durability and help ensure that it'll survive harsh and rigorous use.

Dual-phase steel

Class of steel alloys that consist of martensite in a matrix of ferritic iron. Dual-phase steel alloys can be highly ductile as well as very strong, and are of interest as next-generation steel armor materials.

Dual-hardness steel

Composite steel material, generally consisting of a high-carbon martensitic tool steel plate metallurgically bonded to a low-carbon steel backup plate of greater toughness but inferior hardness. Thus conceptually similar to ceramic composite armor. Dual-hardness steel is produced primarily via a method called roll-bonding, which is complex and expensive to perform, and doesn't always result in good interfacial properties. Thus, because it is expensive to make and complicated to get right, dual-hardness steel is a very uncommon material. A more favored approach to the same end is to use ultra-high hardness steel applique or up-armor kits on top of RHA structural armor.

Ductile perforation

Ballistic penetration mechanism, also called "pushing aside," where the projectile forces its way through the target by displacing the target material. Bulges build up around the site of impact where the target material has been pushed aside, the projectile compresses the interior of the target as it continues to travel through the plate, and bulges form again on the rear side of the target as the projectile pushes through. Ductile hole growth is most common when a hard projectile strikes a softer target. Ductile perforation can be an effective way to rob projectiles of kinetic energy, so is often favored over other penetration mechanisms in the design of laminated steel armor systems for combat vehicles.

Dwell

Phenomenon in the penetration mechanics of ceramic armor plates. When an AP projectile with a hardened steel or WC-Co penetrator strikes a ceramic tile that has been bonded to a metal or composite material on its rear face, the projectile core's nose will begin to shatter or erode immediately upon impact, and the rear part of the projectile will decelerate. At this stage, the projectile does not penetrate the ceramic plate, and appears stopped on its surface. This condition lasts only for mere microseconds, however, as compressive stresses are subsequently transferred, at the ceramic's sonic velocity, to the ceramic tile's backer, which deflects in response. (See also: BFD) The deflection of the backer causes all of the ceramic material around the projectile to break up into fragments due to shear stresses, in what's called the fracture conoid. By this time, whatever remains of the projectile — which by now has lost substantial mass and velocity, and may have been reduced to fragments itself — can penetrate through the fragmented material. In a well-designed armor system, the projectile remnants will be stopped by the backer.

Dyneema

Trade-name for UHMWPE fibers and composite materials from DSM.

ECH

Combat helmet derived from the ACH/MICH, but thicker, heavier, and made of a stronger UHMWPE prepreg composite. The ECH boasts extremely good anti-frag performance, can defeat small-arms projectiles such as the 7.62x51mm M80 Ball at roughly 300 yards, and can also presumably defeat the 7.62x39mm MSC at common engagement distances. Generally incapable of defeating rifle rounds with harder steel cores, such as the M855, 5.45x39mm 7N6, or similar. Effectively identical to the ACH/MICH in all other respects, such as shape, padding, blunt impact performance, and appearance.

EFP

Explosively formed projectile, or explosively formed penetrator. Also called "self-forging fragment," or SFF. A variant of the shaped charge weapon. Generally, a heavy metal cylinder filled with an explosive chemical mixture, capped on one end with a relatively thin metal dish, usually of iron or tantalum, though copper is sometimes used. When the explosive detonates, that metal dish is propelled outwards at a velocity of roughly 2000 meters per second (about 6500 fps), and its edges collapse inwards so that its shape comes to resemble a shotgun slug. EFP armor penetration is inferior to that of shaped charge jet weapons, but they are much less sensitive to standoff distances and can be initiated dozens of meters away from their target. Because of their simplicity, ease of manufacture, and great efficacy against armored vehicles, the EFP is a popular type of IED. There is no conceivable body armor system that will stop an EFP. Against armored vehicular targets, the EFP doesn't penetrate armor as well as the shaped charge jet, but does substantially more damage if it does successfully penetrate — so the EFP is preferred against lighter targets, whereas the shaped charge jet weapon is primarily employed against the most heavily armored vehicles.

E-Glass

Alumino-borosilicate fiberglass. The oldest of the strong fibers, E-Glass resin composites were used in military flak-jackets and other articles of protective gear from the 1940s onwards, sometimes under the trade-name "Doron." E-glass is largely obsolete in body armor today, though there is some residual use in hard armor plate backers. E-glass is, however, still very common as the primary material in the crew-side spall-liners of armored combat vehicles. Originally developed for electrical insulating equipment, the "E" stands for "Electrical."

EPP

Polymeric foam derived from polypropylene; "EPP" stands for "expanded polypropylene." Exceedingly light and tough, though quite hard and stiff, EPP is frequently used in helmet pads, such as the pads that ship with the Ops-Core FAST helmet. It is less frequently used in body armor.

Epoxy

Epoxy resins are a large family of reactive organic liquids that are characterized by the presence of an ethylene oxide (oxirane) group. They react with hardeners to form cross-linked polymers of high strength and good adhesion to a wide variety of substrates. Epoxy adhesives come in a dizzying range of types, with widely variable mechanical properties and bonding characteristics. As a general rule, though, epoxies are less flexible and less ductile than polyurethane-based adhesive resins, and have poorer impact resistance — but, at the same time, they are much stronger, more rigid, and they bond more firmly to a wider variety of substrates. Epoxies are the matrix of choice for carbon fiber and some fiberglass fiber-composites. UHMWPE and aramid, however, tend to utilize different matrix materials such as polyurethane or phenolic resins. Epoxies are also useful in the bonding of a ceramic tile to its backer in ceramic composite armor systems.

EPS

Polymeric foam derived from polystyrene; "EPS" stands for "expanded polystyrene." Much like EPP, EPS is exceedingly light and tough, though quite hard and stiff, and has seen considerable use in helmet and hard armor plate padding. EPS is closely related to styrofoam, which is foamed and extruded polystrene.

ESAPI

SAPI variant known to afford protection from the .30-06 APM2 projectile. Slightly thicker and heavier, thus. In all other respects identical to the SAPI: The ESAPI is ceramic composite, multi-curved, ICW, utilizes a monolithic ceramic strike face, and is tested to military specifications rather than to NIJ specifications.

Exoskeleton

In a military context, external load distribution system. Passive exoskeletons redistribute weight and pressure from the torso to the hips, and from the hips to the ground. These are currently in-use by Chinese and Russian military forces — and the UK's current Virtus armor system incorporates a few similar features. Powered exoskeletons incorporate motors and servos at joints, to substantially improve wearer strength and stamina, and theoretically enable the use of very thick and robust armor plates. For this reason, powered exoskeletons that incorporate armor plates are often referred to as "power armor" — a term with a very long pedigree in Western popular culture, dating back to the 1950s and Heinlein's "Starship Troopers." Powered exoskeletons are, however, severely limited by current battery technologies, and are not in regular use anywhere.

Explosive reactive armor, ERA

System designed specifically to counter the threat shaped charge weapons pose to heavy armored vehicles. An explosive reactive armor module consists of two sheets of steel, each about 1 to 3mm in thickness, with an explosive chemical mixture sandwiched between them. When the module, which is also called a "cassette," is struck by a shaped charge jet, the explosive detonates and both steel sheets are propelled at a high velocity, typically in the middle of the ordnance velocity range. One sheet is generally pushed against the body of the armored vehicle, whereas the other is pushed away from the armored vehicle into shaped charge jet itself. Both sheets, and the explosive blast-wave, interact with and disrupt the shaped charge jet. ERA is usually sloped to maximize asymmetrical interactions with, and deflection of, the shaped charge jet. Although ERA is the most effective armor system against shaped charge jets, it is considerably less effective against long rods and other kinetic energy penetrators. For obvious reasons, ERA has not been scaled-down for use in body armor.

FBI rated

Article of soft armor that has been successfully tested to the US Federal Bureau of Investigation's in-house ballistic specifications. Like the DEA specification (see: DEA rated) the FBI test protocols involve extensive high-temperature and low-temperature conditioning requirements, and contact shot requirements, that are far in excess of what the NIJ protocols demand. Unlike the DEA specification, the FBI specification does not require that soft armor be tested against fragment simulating projectiles. Successful compliance with the FBI rating is a mark of quality in soft armor.

Fiber

Natural or synthetic substance much longer than it is wide. Thin fibers are substantially freer of microstructural defects than bulk materials, and those defects are often the points which initiate the failure of the material, and it is largely for this reason that, e.g., fiberglass is far stronger and tougher than plate glass. Ballistic fabrics and fiber composites derived from synthetic fibers — such as carbon fiber, UHMWPE, aramid, M5, and others — can attain higher strength-to-weight ratios than any other class of material.

Fiber breakage

The dominant ballistic penetration mechanism in fiber composites and ballistic fabrics. Occurs when the strain induced by impact is higher than the failure strain of the target's fibers, resulting in the fracture of the fibers.

Fiber composite, fiber-reinforced plastic, FRP

Polymer such as epoxy, nylon, vinyl ester, polyurea, polyurethane, polypropylene, or phenol formaldehyde reinforced with a natural or synthetic fiber for enhanced strength, stiffness, and toughness. The fibers can be chopped strands, e.g. in glass-fiber reinforced nylon, or they can be continuous ballistic fabrics, e.g. in all prepregs and most grades of Dyneema and Spectra-Shield UHMWPE. The vast majority of the fiber materials used in armor are utilized in fiber composite form; aramid is the *only* tough fiber that's commonly used solo, as a neat fabric. UHMWPE-polyurethane is the most popular modern fiber composite system, and is now the material of choice in every body armor application which doesn't require optical transparency: Helmets, hard armor plates and plate backers, and soft armor panels.

Fiberglass

Once a trade-name for specific brands of E-glass-based fiber reinforced plastics, now a totally generic term used to describe all glass fibers and glass fiber composites in a general sense. See also: E-glass, S-glass.

Filler

Any inert foreign substance added to a bulk, non-fiber polymer to improve or modify its properties. In an armor and military equipment context, these will typically be chopped glass fibers or carbon fibers, added to improve stiffness and strength at the cost of ductility. e.g., the very widely popular "glass-reinforced nylon."

FMJ

Full metal jacket. A metallic bullet encased in a layer, or "jacket," of a different metal alloy. The bullet is most frequently made of lead, mild steel, or a combination of both. The jacket is typically made of a soft copper-zinc alloy known as gilding metal, but can also be made of treated or surface-coated steel.

Foam

Cellular material with high porosity. “Open cell” foams are a sponge-like, skeletal polymeric or crystalline network, generally filled with whatever gas or liquid medium they find themselves in — which, most of the time, is air. “Closed cell” foams contain trapped gas bubbles that do not form a continuous network in the material, and foams of this class do not absorb air or water from the surrounding medium. The most common foam materials used in armor are EPP, EPS, and polyurethane derivatives. Metal foams are typically open cell foams, and are often called “metal sponge.” Composite metal foam, “CMF,” describes a closed-cell metal foam where hollow metal spheres are embedded in a solid metal matrix. See entry for “composite metal foam.”

Fracture conoid

Phenomenon in terminal ballistics. The “fracture conoid” is a characteristic inverted cone pattern of fractured and comminuted material which rapidly forms when a high-speed kinetic energy projectile, e.g. a rifle round or a long rod, strikes a ceramic tile bonded to a tough backer. This conoid, which is smallest in diameter on the strike face and largest in diameter at the interface between the ceramic tile and its backer, typically has a base diameter of approximately two to three projectile diameters from the center of impact, and a semi-angle of 60-70°. (68° is often used for modeling purposes.) It has plausibly been theorized that the fracture conoid is an essential kinetic energy dispersal mechanism; that ceramics which have been tuned to form larger-diameter coniods will perform better upon ballistic impact, whereas ceramics that don’t form proper conoids should exhibit poor performance. Fracture conoids can form in brittle metals, such as certain high-strength beta titanium alloys, certain grades of tool steel, and amorphous metals — but only when these metals are bonded to a backer. If they’re not bonded to a backer, they will, instead, shatter.

Fragmenting munition

General term for any weapon consisting of high explosive inside a vessel, where, upon initiation of the explosive, metal fragments or shards are propelled outwards at a high velocity. In most instances, at least where real military ordnance is concerned, the fragments will initially attain velocities in the ordnance velocity range — around 1000 – 2000 m/s. (3250 – 6500 feet per second.) But because fragments are typically irregular and not particularly aerodynamic in shape, they decelerate rapidly and their trajectories are unstable. Fragments can often quite easily be stopped by armor, on account of poor sectional density. Many military armor systems are tested with FSPs and RCCs to try and assess their performance against fragmenting munitions, and are classified solely based on their performance against these particular threats — that is, many military armor systems are not tested against small-arms threats at all. This may make some degree of sense, as fragmenting muntions are responsible for the majority of battlefield casualties since WWII, typically holding a roughly 70% share — something that is also true of the recent conflicts in Iraq and Afghanistan, as most IEDs are fragmenting munitions of a sort.

Fragments

Small shards or pieces of metal, propelled outwards at a high velocity due to an impact or explosion. Fragments can be regular or irregular in shape, come in a wide variety of sizes, and can be made of almost any metallic material. Fragment velocities peak at about 2000 meters per second (6500 feet per second) adjacent to particularly violent explosions, but decelerate rapidly, and usually impact at fairly low velocities. See: Fragmenting munition.

FSP

Fragment simulating projectile. Fragmenting munitions often disperse high-velocity fragments that are of irregular shape, and can exhibit variable velocities and ballistic characteristics. FSPs and RCCs were developed in an effort to standardize armor testing against fragmenting munition threats. FSPs are generally chisel-nosed cylinders, made of AISI 4340 steel, and hardened to roughly 30 HRC.

Functionally graded material, FGM

Two component composite material characterized by gradual changes in properties and composition across the through-thickness dimension. Best illustrated by reference to a real-world FGM: An armor plate that on one side is pure titanium metal, on the other side is pure titanium diboride, and, in-between, is a gradient of mixed Ti-TiB2 cermet / metal matrix composite — metal rich on the titanium side, equally mixed in the center of the plate, and ceramic rich on the TiB2 side. FGMs are typically prepared via powder metallurgical techniques, and can be incredibly complex to manufacture in bulk quantities, due to complexities with respect to proper mixing, sintering temperatures, grain growth during sintering, etc. In the early 1970s, titanium-based and beryllium-based FGMs had been identified as ultra-high-performance armor materials which can combine the surface hardness of ceramics with the ductility of metals, but the impossibility of their industrial manufacture has sidelined them ever since.

Gilding Metal

Brass alloy with high copper content and low zinc content, typically between 89-95% copper and 5- 11% zinc. Soft and extremely ductile, gilding metal is most commonly employed in bullet jackets, where it engraves with the gun's rifling and produces a gas-seal as the bullet travels up the barrel. See also: Jacket.

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Glass ceramic

Dual-phase material, chemically and structurally complex, derived from the partial recrystallization of silicate glass. Whereas glass is entirely amorphous, glass-ceramics are roughly 90% polycrystalline, with an amorphous secondary phase. Reasonably hard, moderately tough, and boasting an impressively low density of just 2.5 gm/cc, lithium aluminosilicate glass ceramics have seen use in high-end and mid-range composite armor systems, particularly against ball round threats. They can be transparent, and are sometimes also utilized in ballistic glass assemblies.

GOST

ГОСТ, *go*sudarstvennyy *st*andart, translates to "government standard." In practice, "GOST" is a huge set of technical standards and specifications overseen by the Euro-Asian Council for Standardization, Metrology and Certification (EASC), which includes Russia, Belarus, Moldova, and a number of Caucasian and central Asian republics as members. (Ukraine withdrew cooperation in 2014.) There are a number of GOST specifications which relate to ballistic armor, helmets, and other articles of protective apparel. The most noteworthy of these, GOST R 50744-95, describes a particularly stringent and demanding test protocol for soft and hard body armor, which is the dominant armor testing protocol in Russia and the other EASC nations. It is continually revised, with the most recent amendments having taken place in 2017.

Graphene

Flat sheet, just one atom thick, of sp2-bonded graphitic carbon. In principle, graphene is much like an unrolled carbon nanotube — and, much like carbon nanotubes, graphene is presently under investigation as a reinforcing material in ceramics, metals, and polymers. (Where the latter is concerned, much along the lines of fiber composites.) Early results are equivocal and do not seem particularly promising. Multi-layer polycrystalline graphene is, effectively, mere graphite.

Hard Armor, Hard Armor Plate

Terms which most frequently refer to hard body armor plates — see: hard body armor — but which can also refer to ballistic shields, barriers, and other rigid, non-flexible articles of ballistic armor.

Hard Body Armor

Rigid body armor plate, typically of ceramic composite, steel, or fiber composite construction. Typically intended to provide protection from rifle rounds, and typically worn inside an armor carrier.

Heracron

Trade-name for aramid and aramid-composite materials from Kolon Industries.

High entropy alloy

Crystalline metallic alloy without a base metal. The traditional definition is "alloys containing at least 5 elements with concentrations between 5 and 35 atomic percent." So, for example, an alloy comprised of 20% aluminum, 20% silicon, 20% iron, 20% cobalt, 10% nickel, and 10% manganese would be a textbook high entropy alloy. Such alloys have extremely high atomic and crystalline complexity. With respect to mechanical properties, some high entropy alloys are hard and strong but brittle, and so resemble amorphous metals; others are extremely tough, even at cryogenic temperatures. High entropy alloys are difficult to manufacture, but are of great interest as next- generation armor materials. They are also of interest as projectile materials; recent scientific work has identified self-sharpening, tungsten-rich HEAs, which may be capable of replacing depleted uranium in certain long rod munitions.

HOSDB

The Home Office Scientific Development Branch (HOSDB) is Britain's equivalent of the NIJ. As the NIJ is the research and development arm of the US Department of Justice, so the HOSDB is the R&D arm of the UK's Home Office. (The Home Office is roughly equivalent to the US Department of Homeland Security.) Among many other responsibilities, the HOSDB is tasked with developing standards and testing protocols for police body armor in the UK, and maintains a list of certified products. The HOSDB 2017 body armor testing protocols were developed exclusively for UK police officers, and do not contain a level where armor is tested against AP projectiles. The proposed NIJ 0101.07 standard was influenced by the HOSDB's body armor testing standards, particularly in how it organizes its different levels.

Hot Pressed

Refers to ceramic parts that were produced — that is, transformed from ceramic powders into dense ceramic bodies — via hot press sintering as opposed to conventional (pressureless) sintering or reaction bonding. Conceptually, hot pressing is simply a process where a ceramic powder is sintered under mechanical pressure. This is commonly done in a uniaxial press, and the pressures involved are generally on the order of 10-50 MPa. The temperatures required are comparable to conventional sintering temperatures — ranging from 900-2300°C for the vast majority of ceramic materials.
Hot pressing is among the oldest and simplest ways to make ceramic parts, for two key reasons.
(1) All known ceramics — save only those few that, like diamond, require ultra-high pressures — are amenable to hot pressing. Indeed, there are many ceramic materials, such as titanium diboride, that can only be manufactured via the hot press, and boron carbide itself was in this category for a very long time.
(2) It's extremely straightforward from a chemical perspective. Sintering aids are usually not required.
…And yet hot pressing is also the most troublesome method, for three very simple reasons:
(1) It is very slow, because the process takes at least 2-3 hours per sintering cycle, and few parts can be made per cycle.
(2) There are severe size and geometry limitations.
(3) It is a very energy-intensive process.
Ultimately, it's extremely difficult to scale the production of hot pressed ceramic parts. So, therefore, hot pressed ceramic parts are uncommon and very expensive, and hot pressing as a method is severely depreciated. It is primarily used for small-batch and research-grade materials, and for the production of TiB_2 ceramics for industrial purposes. Boron carbide owes all of its recent popularity to the fact that sintered and reaction bonded grades have become available.

Hypervelocity impact

Impact at velocity over 2000 meters per second. (6500 feet per second.) Faster than the ordnance velocity range, with correspondingly more extreme terminal ballistic events and altered ballistic penetration mechanics. Hypersonic missiles are hypervelocity weapons, as are shaped charge jets, but there are few others in current military use. However, the study of hypervelocity impacts is of key interest to the designers of space systems such as stations and satellites, for micrometeroids typically travel at hypervelocities — their *average* velocity is 20 km/sec or roughly 65,000 feet per second. At such speeds, solid materials are dynamically unstable and impacts are immediately explosive. Somewhat paradoxically, this explosion-upon-impact trait makes hypervelocity micrometeroid impacts quite predictable and easy to armor against, e.g. in the "Whipple Shield."

IBA

"Interceptor Body Armor." US Military body armor system which was first issued in 2001 as a replacement for the aging PASGT system. Essentially a body armor carrier with a pocket for a soft armor panel that was slightly more advanced and robust than the first-generation Kevlar 29 soft armor that was used in the PASGT. Also contained integral pouches for SAPI and later

ESAPI rifle plates. Not received favorably by troops on account of its bulkiness and lack of modularity, the IBA was swiftly replaced by the IOTV.

ICW

"In conjunction with." Armor system, typically a hard armor plate, that is designed to be worn or placed on top of a separate armor system. A plate that is marked "Level IV ICW Level IIIA soft armor" offers protection to the NIJ Level IV specification if, and *only* if, it is worn over a Level IIIA soft armor panel. The level of protection that such a plate offers as a standalone system is usually not specified. Military SAPI plates are ICW; intended to be worn over general-issue soft armor. The ICW hard armor plate is a variant of the appliqué armor concept, so see also: appliqué.

IHPS

As of this writing, the IHPS is the US military's newest helmet system. Made primarily of ultra high molecular weight polyethylene, it is derived from the ECH and offers similar baseline ballistic protection, but was designed from the ground up to interface with modular accessories such as a ballistic mandible for face protection, a frontal ballistic applique for improved performance against small-arms threats, and a drop-in polycarbonate visor for eye protection. The shape of the IHPS is slightly different from previous US military helmets, but the area of protective coverage is similar. Unlike the ACH and ECH, the IHPS is boltless — there are no holes drilled through the shell. The IHPS offers slightly improved blunt impact performance, as well, relative to the ACH and ECH. Feedback from users has, however, been mixed; the average soldier has little use for those accessories, and, at three pounds for a baseline Size M and roughly six pounds with all accessories installed, the IHPS is viewed as being excessively or unnecessarily heavy.

Integral armor

Armor that serves a structural load-bearing role in addition to a protective role, e.g., the metal hull of a combat vehicle. Also known as structural armor. One of the key shortcomings of ceramic materials is that they can't be used in structural applications due to their brittle nature and lack of impact resistance, and fiber composites are often too highly anisotropic, so most if not all examples of integral armor are metallic in nature. The search for high-performance integral armor materials is a main driver of research into high-strength aluminum alloys.

Interface

Describes the boundary between two different materials or layers of material. Fiber composite and ceramic-composite armor systems are always layered, and thus contain multiple interfaces. For instance:

(1) Between the cladding layer on the strike-face of the ceramic tile and the ceramic tile itself;
(2) Between the rear face of the ceramic tile and the backer material;
(3) Between the layers of the backer material, if it is a multi-layered fiber composite;
(4) Between the backer material and any foam utilized on the body side of the armor plate;
(5) Between the armor plate and the fabric wrapping or polymer coating used to finish and waterproof it;
(6) between the armor plate and the wearer's body.

These interfaces can dominate system performance, particularly where a ceramic tile is not properly joined to its backer. Adhesive and resin properties, airgaps, and the acoustic impedance values of materials are important factors to take into consideration in the design of armor systems.

Interface defeat

Describes a condition where a high-velocity projectile, such as a long rod, is stopped on the surface of a ceramic tile. Generally achieved only when thick ceramics are placed in confinement, are under compressive pressures, and are used in combination with shock-attenuation and wave-damping subsystems. That said, extremely thick ceramic tiles — thicker than those normally used in combat vehicles — are naturally capable of achieving the interface defeat of small arms projectiles, including AP projectiles, even without any assistance from complex systems configurations. On that score, an interesting experiment was once performed where a 200x200x200mm cube of alumina was struck by a .50 APM2 projectile. The cube defeated the round handily, didn't chip or fracture, and was hardly even dented.

Intermetallic

Ceramic-like material derived from the combination of two metallic elements, where the resulting compound has an ordered molecular structure that is distinct from its constituent metals. Aluminides, such as the titanium aluminide Ti_3Al, are common intermetallics that, in pure form, see use in niche aerospace and industrial applications. Lightweight beryllides such as $TiBe_{12}$ can exhibit better hardness-to-weight ratios than the vast majority of ceramics, but are vanishingly rare on account of the many *severe* difficulties associated with beryllium processing. Certain intermetallics form *in situ* in metal alloys such as maraging steels and nickel superalloys, which are often strengthened by those intermetallic precipitates.

Impedance, acoustic impedance

Measure of the ease with which a pressure wave (also "stress wave" or "sound wave") propagates through a material. Generally, and very simply, the acoustic impedance of a material equals that material's density times the speed of sound in that material. ($Z=pV$) Thus high-density, high-sonic-velocity metals like tungsten have the highest acoustic impedance values; low-density, high-sonic-velocity metals and ceramics like beryllium and silicon carbide have lower but still substantially high acoustic impedance; low-density, low-sonic velocity foams and

polymers have
exceedingly low impedance.
Pressure waves don't travel freely from one medium or material to another. The greater the impedance mismatch, the more those waves bounce-off at material interfaces. Assume we have a composite armor plate comprised of a tungsten sheet bonded with a polyurethane adhesive to a polyethylene sheet. If that plate is struck on its tungsten side, less than 1% of the resulting pressure wave will travel through the polyurethane adhesive and into the polyethylene plate. Because of the impedance mismatch, 99% of the pressure wave will be reflected back into the tungsten sheet at the adhesive interface.
This is an important concept in terminal ballistics. In ceramic composite armor design, some care should be taken to match the impedance of the adhesive to the ceramic layer, or the reflected pressure wave will ring through the ceramic layer and increase its damaged area. Generally, impedance-matching techniques improve energy transfer and performance, and reduce damage to the armor's strike face. But, in metal armors struck by hard-cored AP rounds, a low impedance between the armor plate and its backer can enhance stress-wave reflection back into the projectile itself, increasing the projectile's breakup or erosion, and improving performance.

IOTV

Improved Outer Tactical Vest. US military body armor system which replaced the IBA, which itself replaced the PASGT. First issued 2007, and still standard issue as of 2021, the IOTV is effectively an armor system which comprises a carrier, an aramid-based soft armor insert that covers most of the torso, and pockets for SAPI-style armor plates and side plates. Deltoid and groin coverage optional.

The IOTV is slightly less bulky and more modular than the IBA it replaced.

Jacket

Thin layer of a soft metal alloy surrounding, and encasing, a bullet's core. If the bullet core is made of lead, the jacket prevents lead fouling in gun barrels; if the bullet core is made of steel, the jacket prevents excessive barrel wear and ensures a tight gas seal as the bullet moves up the barrel. Jackets are typically made of gilding metal, but are often made of other copper alloys. Mild steel and pure copper jackets are less frequently utilized, but are not terribly uncommon. Jackets average about 0.7mm thick — which, particularly in a 5.56mm or smaller projectile, means that the jacket can make up a substantial fraction of a bullet's total volume.

JHP

Jacketed hollow point. A jacketed (see FMJ) bullet with a cavity in its nose to facilitate expansion upon impact and maximize energy transfer. JHP bullets are poor at armor penetration, but maximize energy transfer onto soft targets.

JSP

Jacketed soft point. A jacketed (see FMJ) bullet where the soft lead nose is left exposed and un-jacketed to facilitate expansion upon impact and improve energy transfer. Like JHP bullets, JSPs are inferior to FMJ rounds at armor penetration, but offer improved energy transfer onto soft targets.

Kevlar

Trade-name for aramid and aramid-composite materials from DuPont.

Kraton

Trade-name for a family of polystyrene-elastomer block copolymers widely used in the manufacture of UHMWPE composites. Some of the most popular grades of Dyneema and Spectra-Shield utilize a Kraton matrix.

Lead

Toxic metal that, on account of its extreme softness, malleability, ductility, natural abundance, and high density (11.35 gm/cc), has been used in projectile weapons for hundreds if not thousands of years. Gradually being replaced in military service by “green projectiles” like the M855A1 and M80A1, which swap lead for copper and hardened martensitic steel. Lead’s legal status as a projectile material is under threat in the EU; it may soon be wholly replaced with bismuth, copper, or steel.

Level I

Describes body armor that complies with the obsolete NIJ 0101.04 Level I specification. Level I armor is usually soft, made from a few layers of aramid-based ballistic fabrics, and was the first type of police body armor introduced. At the time of its introduction, in the mid 70s, relatively low-power handgun rounds such as the .22 and .380 were the most common threats faced by police, so Level I armor was designed to be as thin and as light as possible while still countering those threats. For various reasons — which includes the proliferation of more potent threats such as the 9mm FMJ, which was uncommon in the mid 1970s but is the single most common threat today — Level I armor is no longer made or certified.

Level IIa

Describes body armor that complies with the largely obsolete NIJ 0101.06 Level IIa specification. Like Level I armor, Level IIa usually describes soft armor. Level IIa armor is built to resist 9mm FMJ and .40 S&W FMJ projectiles at standard handgun velocities.

Level II

Describes body armor that complies with the NIJ 0101.06 Level II specification. Like the levels that precede it, Level II usually describes soft armor, and is tested against 9mm FMJ +P and .357 Magnum. Though less popular overall than Level IIIa, this level probably represents the "sweet spot" insofar as soft armor protection-to-weight and protection-to-thickness ratios are concerned, for it is usually substantially lighter and thinner than Level IIIa armor, and yet will still stop >99% of the threats police and civilians are likely to encounter on the street. Level II armor is, broadly speaking, capable of compliance with the more stringent DEA and FBI armor test protocols. The soft armor used in modern military systems such as the IOTV is, in principle, rated to Level II.

Level IIIa

Describes body armor that complies with the NIJ 0101.06 Level IIIa specification and is rated to stop high velocity .44 Magnum and .357 Sig handgun rounds. At present, the most popular soft armor systems are rated at Level IIIa; hard armor plates are, on occasion, also rated to Level IIIa. As the .44 Magnum threat is exceptionally rare — as of 2021, it was used in only one police shooting over the previous ten years — Level IIIa soft armor has a well-deserved reputation for being over-built.

Level III

Describes body armor that complies with the NIJ 0101.06 Level III specification and is rated to stop 7.62x51mm M80 NATO Ball at approximately 2800 feet per second. With only rare exceptions — such as LIBA pellet armor and Hexar flexible rifle armor — Level III armor systems are hard body armor plates. The Level III rating is fraught with problems, which have given rise to the vague, unofficial, and ambiguous "Level III+" rating. The primary problem is that although the Level III standard is supposed to describe body armor that is capable of dealing with rifle ball rounds, the 7.62x51mm M80 projectile is an uncommon threat, and, more to the point, it is a threat that doesn't share penetration mechanics and ballistic characteristics with those threats that *are* common. There is an abundance of "Level III" plates that will stop M80 Ball, but will not stop the very common 5.56x45mm M855 — even if the M855 strikes at a sharply reduced velocity. There is an even greater abundance of steel body armor plates that will stop M80 Ball, but will not reliably stop the 5.56x45mm M193 at anything near muzzle velocity — and M193-style threats are *the most common* rifle threats in America by a substantial margin. The clear majority of Level III plates are unable to stop emerging "ball round" threats like the M855A1. So although "Level III" was intended to denote armor that is capable of standing up against most common ball round threats, it really does nothing of the sort, and says very little about the expected performance level of an armor plate. Steps are being taken to rectify this problem in the NIJ's forthcoming 0101.07 specification; .07's "Rifle 1" rating will purportedly test armor against the 5.56x45mm M193, the 7.62x51mm M80 Ball, and the 7.62x39mm Type PS mild steel core; "Rifle 2" includes all three of those, and adds the 5.56x45mm M855.

Level III+

As the NIJ 0101.06 Level III specification is inadequate in many respects, the majority of hard body armor manufacturers now sell systems under a "Level III+" designation. "Level III+" does not exist in the NIJ's rating system, and it has no clear, unambiguous definition. It seems to have one lax, and almost deceptive, definition: "Armor that is in compliance with NIJ 0101.06 Level III, and also defeats a small arms ball projectile, at muzzle velocity, not included in NIJ 0101.06." The small arms projectile in question is often 5.56x45mm M193, 5.56x45mm M855, *or* 7.62x39mm Type PS mild steel core. In practice, what this means is that there is armor sold as "III+" that won't defeat M193 or M855! There is also a more stringent definition: "Armor that is in compliance with NIJ 0101.06 Level III, and also defeats 5.56x45mm M193, 5.56x45mm M855, *and* 7.62x39mm Type PS mild steel core — all at muzzle velocity from a long barrel." This latter definition is reflected in the forthcoming NIJ 0101.07's rifle threat ratings; "Rifle 2" corresponds to this precise definition of "Level III+" and should obviate the need for any ad hoc intermediate ratings.

Level IV

Describes body armor that complies with the NIJ 0101.06 or 0101.04 Level IV specification and is rated to stop at least one shot of .30-06 APM2 at approximately 2880 feet per second. The APM2 — an extremely tough test for any armor plate — has featured in the NIJ's tests from the early days of the 0101.00 specification, and looks as though it is set to continue as the "Rifle 3" test projectile in the forthcoming 0101.07 specification.

LIBA

Trade-name for the most noteworthy variety of pellet armor. Also licensed to General Dynamics as "SURMAX." See: pellet armor.

Liquid armor

Generally a reference to aramid ballistic fabrics saturated in a colloidal fluid which contains small ceramic, glass, metal, or mineral particles. The fluid may be shear thickening, which means that it locks up and stiffens as impact forces are applied. Alternatively, the fluid component may be magnetorheological, which means that it increases in viscosity and stiffness as a magnetic field is applied. This class of material has been researched for nigh on two decades, but has never been commercialized — because the performance of these systems is less than spectacular, and because liquid armor is difficult to produce in a stable way. After all, liquids flow, and it is very difficult to maintain a stable and uniform distribution of liquid inside an armor panel; in practice, most of the liquid eventually flows to the bottom of the sealed armor panel and pools there.

There is a second definition, though a much less common one: External water tanks have shown considerable efficacy as armor against shaped charge jet weapons — on a weight basis, exhibiting performance anywhere from roughly 2x to roughly 4x superior to RHA — with an optimal thickness around 50cm, and with diminishing returns at greater thicknesses.

Liquid Crystal Polymer

Any polymer with a tendency to form ribbon-like crystals in the liquid state. Polymers forming crystals in the melt are called thermotropic liquid crystal polymers, whereas polymers forming crystals in solution (e.g., when dissolved in acids) are referred to as lyotropic. Aramid Zylon, and the polyarylate Vectran are all liquid crystal polymers, but the generic term "Liquid Crystal Polymer" or "LCP" typically refers only to Vectran.

Load Distribution System

Technology utilized in soldier-borne equipment systems that distributes weight from weaker to stronger areas of the body. In a military context, the most common load distribution systems in use today are hip belts that have rigid connections to body armor carriers. Those rigid supports redistribute the weight of the armor carrier, so that it's supported less by the muscles of the torso, and more by the hips and legs. The UK's Virtus armor system prominently features just such a load distribution system. Passive exoskeletons are much along the same lines, but constitute a complete external system, and contain lower-body supports to redistribute weight from the hips to the ground. (See: exoskeleton.)

Long rod

Long projectile, typically dart-shaped and fin-stabilized, with a length-to-diameter (L/D) aspect ratio of 20-30. Used primarily in tank main gun ammunition, e.g. in armor-piercing fin-stabilized discarding sabot (APFSDS) rounds. Typically made out of tungsten heavy alloy or depleted uranium. Long rod muzzle velocities are on the high-end of the ordnance velocity range — typically around 1500 to 2000 m/s (5000 – 6500 fps) — and, because they are highly aerodynamic, they shed very little velocity in flight, even over distances of a mile or more. They are very highly effective against armor, on account of their high striking velocity, their considerable mass, and their extreme sectional density. Long rods are generally better at defeating modern armored targets than other types of tank main gun ammunition, such as HESH and HEAT rounds.

M193

Refers to 5.56x45mm M193 Ball, a common small-arms projectile used in ballistic armor testing. The bullet is of simple, all-lead construction, enclosed in a gilding metal copper-zinc jacket. It weighs 55 grains, or 3.56 grams. Because the bullet is so small, its jacket-to-core ratio is relatively high, which can somewhat improve its performance against hard targets. Muzzle velocity from an M16 rifle with a 20" barrel is roughly 3,270 fps, and velocities of up to 3400 fps are attainable with longer 22" to 24" barrels. The M193 generally performs poorly against most types of body armor, but is well-known for the peculiar and seemingly paradoxical fact that it can reliably penetrate steel armor plates, where heavier or seemingly more potent rounds like the M80 and M855 fail. This has to do with the M193's terminal ballistic behavior at high velocities, and has been extensively covered in its own article on the Adept knowledgebase. Other high-velocity lead-cored rounds such as .270 Winchester exhibit the same terminal ballistic behavior, and also reliably over-perform against steel armor. The M193 is included in the NIJ's forthcoming .07 ballistic armor specification, as an RF1 threat.

M2 AP

See "APM2."

M5 Fiber

Extremely strong "rigid rod" fiber derived from highly-aligned chains of the polymer polyhydroquinone-diimidazopyridine. M5 was developed around 1999, and composites derived therefrom were tested by the US Military around the turn of the century. These preliminary composites performed well, and impressed the respected armor scientists tasked with analyzing it, but the material was never developed further. This is unusual, for it is theorized that a modern M5 fiber composite should exhibit performance highly competitive with the best UHMWPE composites, and M5's thermal and chemical stability was tested and found to be highly robust. M5 is also structurally strong and stiff, in a manner similar to carbon fiber, which should enable its use in structural roles. M5 seems to have just gone off-patent, and may now see renewed interest.

M80 Ball

Refers to the 7.62x51mm M80 NATO Ball, a common small-arms projectile used in ballistic armor testing. Like the M193, the bullet is of simple, all-lead construction, enclosed in a gilding metal copper-zinc jacket. It weighs exactly 10 grams, or 147 grains. Muzzle velocity from an FN FAL with a 21" barrel is roughly 2,756 fps. The M80 Ball was introduced in the 1950s, but was quickly superseded in general infantry use by the 5.56x45mm M193. It is still in use in niche applications — e.g., in machine-guns, such as the M240, and in designated marksman rifles. In all applications it is being phased out due to the recent introduction of the high-performance M80A1 EPR. The M80 Ball is, nevertheless, the basis for the NIJ Level III armor test specification.

M855

Refers to the 5.56x45mm M855 Ball, a very common standard-issue small-arms projectile, which is effectively identical to the NATO SS109. Frequently used for armor test purposes. The bullet weighs 62 grains (4.01 grams) and consists of a lead bullet with a steel "penetrator" tip, all in a gilding metal

jacket. The tip ID is green. Muzzle velocity is generally ~3,113 fps from a full-length M16 rifle, or ~2,916 fps from an M4 carbine. The M855, as per its specification, is rated to penetrate 3/8" (9.5mm) mild steel at 160 yards. The M855 is noteworthy for two reasons: First, because it has highly unusual performance characteristics. It easily penetrates most armor plates made primarily of UHMWPE, despite the fact that those plates might be rated "Level III" — but, at the same time, it under-performs against most other types of armor, including steel and ceramic-composite armor, largely because its steel penetrator — which is typically round 40 Rockwell C and thus not very hard — readily mushrooms when it impacts a sufficiently hard and strong material, and the lead bullet flows laterally around the steel penetrator, increasing the bullet's contact area on the target. (This is discussed in a separate article on the Adept knowledgebase.) Second, because it is set to become the NIJ's primary "RF2" test projectile. The M855 is not an armor piercing round.

M855A1

Refers to the 5.56x45mm M855A1 EPR, the designated successor to the M855. In limited military use since 2010, but still relatively uncommon, and difficult to obtain on the civilian market. In some respects, similar in construction to the M855; in other respects, very different. The bullet is still 62 grains, still contains a steel penetrator ahead of a slug made from a different metal, and its muzzle velocity is similar, though slightly faster. (3150 fps from a 20" barrelled M16, and 2970 fps from an M4.) But unlike the M855, the M855A1's penetrator is hardened to a near-AP level of roughly 58 HRC, this hardened penetrator is considerably longer and more massive, and the slug behind the penetrator is made of solid copper rather than lead. The projectile is somewhat longer and larger than the regular M855, as well, and thus exhibits a higher sectional density. Its performance against armor is generally extremely good; it can penetrate 3/8" (9.5mm) mild steel at 350 yards, whereas the M855 is only rated for the same performance at 160 yards, and the M855A1 doesn't suffer from performance shortcomings on harder targets. The M855A1 is not used in the official testing of any armor plates at the moment, but is sometimes employed as a particularly potent "special threat."

Magnesium armor

Armor plate made primarily of a magnesium alloy. With a density of just 1.78 gm/cc, magnesium is the lightest metal used in armor, and, strikingly, is also lighter than any ceramic presently used in armor, being roughly 30% lighter than boron carbide. Magnesium alloys are highly castable and can exhibit good specific strength, but, like aluminum, their hardness is very poor. Unlike aluminum, most grades of magnesium are quite expensive, they are highly susceptible to corrosion, and they require fairly complex surface treatments prior to use in any industrial or military application. Magnesium alloys are not currently employed to any substantial extent in body armor, but next-generation magnesium alloys are presently under investigation for use in aerospace and vehicular armor applications. MIL-DTL-32333 is a US

Army specification for magnesium appliqué armor, primarily for ground combat vehicles, and calls for the use of alloy AZ31B. Alloy WE43C has also been promoted as an armor material.

Martensite

Metastable steel microstructure where carbon is kept largely in supersaturated solution, as opposed to in carbide precipitates. Generally produced by heating steel above its austenite transformation temperature and quenching it rapidly in oil or water. Upon quenching, the steel's molecular lattice will transform from austenite's face-centered cubic arrangement to a body-centered cubic or tetragonal structure — a transformation which is associated with changes of volume, increased internal stresses, and the proliferation of crystal dislocations. Ultimately, the result is a stronger and substantially harder metal. As martensite has excellent mechanical properties, is easy to produce, and as the volume fractions of carbides and retained austenite can easily be tinkered with for finely-tuned mechanical properties, martensite is extremely popular in all military applications, including armor. The peak theoretical yield strength of martensitic steel is 3600 MPa; the best armor steels in use right now exhibit yield strengths of roughly 1600-1800 MPa. See also: bainite, pearlite.

Matrix phase

The phase in a composite — which includes ceramic matrix composites, metal matrix composites, polymer composites, two-phase metal alloy microstructures, cermets, etc. — that is continuous or completely surrounds the other, dispersed phase.

Melting

Ballistic penetration mechanism in low-melting point fiber composites and ballistic fabrics — typically affecting those made of UHMWPE or nylon. Occurs when the heat generated by the impact of a projectile, or events related to the firing of the projectile, is higher than the melting point of the target material. A known problem where UHMWPE ballistic fabrics or fiber composites are subjected to contact shots, and possibly a problem where ceramic-UHMWPE composite armor is struck with API projectiles.

Metal Matrix Composite (MMC)

Generally: Metallic material reinforced with a secondary ceramic phase. A metal's thermal properties, and its stiffness (see: modulus), are not amenable to improvement via alloying strategies. Some light alloys are also severely limited in the hardnesses they can attain. For these reasons, ceramic particles are sometimes added to metal alloys, to improve those properties that cannot be improved via traditional alloying. For instance: Copper and aluminum are frequently reinforced with diamond or silicon carbide particles for use in high-performance heatsinks; titanium and steel are often reinforced with titanium diboride particles for an improved stiffness-to-weight ratio; boron carbide powder has also been added to aluminum for better hardness and stiffness. These strategies are typically effective, but have very narrow niche applications, for most of these MMCs are brittle. They typically lack the ductility and damage tolerance of metals, while also lacking the high hardnesses and compressive strengths that characterize ceramic materials. They are infrequently used in armor, but they are much-studied and have been of enduring interest to the military industrial community. Conceptually, the MMC is the mirror image of the cermet; whereas the cermet is a ceramic that contains up to 15% metal content, the MMC is a metal or metal alloy that typically contains up to 15% ceramic content.

There is also a second, much less common definition: "Metal matrix composite" (or "metal matrix nanocomposite") can refer to metal alloys that contain fiber, wire, whisker, or nanoparticle reinforcement. A ceramic matrix composite is something along the lines of this second definition.

MICH

"Modular Integrated Communications Helmet." Combat helmet originally designed for US Special Operations Forces in 1999, but which very quickly became the basis for the US Army's ACH helmet. The MICH is a composite helmet, made of a prepreg derived from woven Kevlar K129 fibers impregnated with a polyvinyl butyral (PVB)-phenolic resin. There are 24 prepreg layers in total, resin content is 16-18% by weight, areal density is roughly 2 pounds per square foot, shell wall thickness is 7.8mm, and the weight of a finished Size L MICH helmet is 3.3 pounds. The MICH was first in a few respects: It was the first US combat helmet to be issued with pads instead of a webbing suspension; it was the first US combat helmet designed to defeat "submachinegun threats," specifically the 9x19mm FMJ NATO round at 1400+50 fps; it was the first helmet with a blunt impact testing requirement (no more than 150Gs upon a drop at 10 fps); lastly, it was the first brimless US combat helmet. The MICH was well-received, and the ACH was quickly rolled out to the rest of the US Army. As mentioned previously, the ACH was derived from the MICH — and it was a close copy indeed, for it incorporated all of the innovations first implemented in the MICH.

Microstructure

The structural features of a ceramic or metal alloy (e.g., grain size, grain morphology, and phase structure) that are generally amenable to observation under a microscope.

Mild steel

Steel with low carbon content — generally up to 0.2% C — without any other intentional alloying additions. Although heat-treatable and often capable of assuming a reasonably hard martensitic microstructure, mild steel is generally ferritic, with small amounts of cementite in the form of pearlite. Because it is predominantly ferritic, it is soft and relatively weak, but very tough and ductile. Mild steel is by a wide margin the most common and the cheapest form of steel, and is used in bullet cores (see: MSC), in structural and architectural applications, in motor vehicle bodywork, etc.

Modulus

Elastic modulis: Measure of a material's stiffness. Young's modulus: A variant of the elastic modulus and also a measure of stiffness. Bulk modulus: Measure of compression resistance, somewhat related to hardness, which is itself a measure of pressure resistance.

Monolithic

In ceramic composite armor, a strike face that is comprised of a single large ceramic tile. As opposed to mosaic or tile-array ceramic composite armor, where the ceramic strike face is comprised of multiple smaller ceramic tiles.

Mosaic

In ceramic composite armor, a mosaic or "tile-array" strike face is one that is comprised of multiple small ceramic tiles arranged in a tessellated manner. Generally, the shapes utilized are hexagons, rectangles, or squares. Triangles may in principle also be used, but would be unavoidably weak around their vertices. No other simple shapes can make for regular tessellation, but complex shapes derived from those simple shapes can also, in principle, be used, e.g. polyhexes or crosses. Mosaic strike-faces can make for improved multi-hit performance, though perhaps at a slight penalty to their single-shot performance-to-weight ratio and thickness. The concept of "pellet armor" was derived from mosaic armor.

MSC

Mild steel core. A full-metal jacket bullet with a core made out of mild steel rather than lead. The mild steel core typically has a hardness of around 200 on the Brinell scale, or around 13 Rockwell C. MSC bullets typically mushroom upon contact with hard targets, and they exhibit poor armor penetration relative to projectiles with harder steel penetrators. They also exhibit poorer soft target performance than projectiles with lead cores. Historically, MSC bullets were employed not because they were particularly effective, but rather because they were cheap and easy to produce in large quantities.

Multi-Curve

Curved in multiple directions, along more than one axis. Generally used to refer to hard armor plates that are multi-curved so as to conform to the human torso. Multi-curve plates are more comfortable to wear than single-curve or flat body armor plates.

Nanocrystalline

Refers to polycrystalline materials where the average grain or crystallite is under 100 nanometers in diameter. Reducing the grain size of metals and ceramics can significantly increase strength and hardness, a phenomenon which is called the "Hall–Petch relationship." Most ceramics and metal materials are at their strongest when their average grain size is roughly 15-30nm in diameter. The Hall-Petch relationship begins to break down, and materials get weaker and softer, once their average grain diameter gets smaller than 10nm. There are many ways to make metal alloys nanocrystalline, but most of them involve subjecting solid metals to mechanical processing — for instance, shot peening a sheet of steel can result in a nanocrystalline grain structure, as the mechanical stresses breaks down and refines that sheet of steel's crystallites. In ceramics, there is only one known method: Take nano-sized ceramic powders and sinter them as quickly and as completely as possible.

NIJ

The US National Institute of Justice: The research and development branch of the US Department of Justice. Among its many other responsibilities, it is tasked with developing standards for police body armor, and is responsible for maintaining the NIJ list of certified armor products.

The first NIJ ballistic armor standard, 0101.00, was introduced in 1973 and contained three ballistic levels; two soft armor types — type .22lr-and-.38 special, and type .357 magnum — and one hard armor type — type .30-06 M2 AP. The soft armor types were intended for nylon ballistic vests, which were quite thick and heavy. In 1975, a Kevlar pilot program was launched by the NIJ, and a thoroughly revised standard, NIJ 0101.01, was released in 1978. This revised standard, now primarily intended for Kevlar vests, included limits on backface deformation, the testing of wet armor panels, more threat levels, and a follow-up testing program for compliant armor solutions. In 1985, 0101.02 was released, which added threat Level IIIa, and angled shot requirements. 0101.03, released a couple of years later, added more instructions with respect to labeling and the measurement of backface deformation in clay. 0101.04 added new threat rounds and implemented some administrative and record-keeping changes. Then, in 2003, the Zylon scandal came to widespread and controversial public notice. An interim 0101.05 standard was quickly released, followed by 0101.06 in 2006. Among other changes, these new standards implemented various "artificial aging" and "accelerated aging" conditioning programs, so as to try and determine whether armor panels would degrade over their service lifetimes.

Although the NIJ's testing protocols for soft armor are adequate overall, if not quite as rigorous as the FBI or DEA protocols, the NIJ's current testing protocols for hard armor have proven inadequate. This is largely due to the proliferation of composite plates made wholly of UHMWPE and steel body armor plates. Both popular types have performance characteristics unanticipated by the people who wrote the protocols, and they can attain a "Level III" rating — which ostensibly means that the armor will stop rifle ball round threats — despite consistent failures against some of the most common rifle threats in America and the world. A new NIJ specification, 0101.07, is soon going to be implemented, and addresses this problem.

Nitride

Ceramic material where a metal or metalloid is combined with nitrogen. As a class, rarely used in armor. Silicon nitride, Si_3N_4, and aluminum nitride, AlN, have been tested extensively in ballistic systems and perform very well relative to silicon carbide and aluminum oxide, but the nitride ceramics are expensive materials, whereas SiC is relatively cheap and Al_2O_3 is *very* cheap. Because cost-efficacy is a key factor — sometimes *the* key factor — in armor acquisition, the nitrides have never gained much of a foothold as armor materials. Boron nitride, BN, exists in two allotropes — and both of them have important industrial uses, but neither one of them is suitable for use in armor. (See: Boron nitride.) Other nitride ceramics — TiN, Mg_3N_2 — have niche industrial uses, but are also unsuitable for use in armor.

Non-deforming penetration

Phenomenon in terminal ballistics. Occurs when a hard projectile strikes a much softer, or loose and granular, material — for instance, when a hardened steel projectile strikes soil, mud, or even concrete. In this scenario, the projectile will not deform significantly, and the depth of penetration is proportional to the ratio of the projectile penetrator's strength to the target's strength.

Nylon

Exceedingly large family of synthetic polymer materials derived from high-molecular weight chains of organic groups connected by amide (CO-NH) linkages. Usually, but not always, manufactured as a fiber. "Ballistic nylon" is a ballistic fabric manufactured from high denier nylon-6,6 yarns woven in a tight 2×2 basket weave, originally intended for use in WWII flak jackets. Its toughness and abrasion resistance proved far superior to its ballistic performance, so it is now totally obsolete as a ballistic material but has become very common in outerwear and tactical gear. See: Cordura. Nylon is also commonly used as a bulk, non-fibrous composite plastic, filled with chopped e-glass or s-glass fibers for enhanced strength and toughness. This is called "glass-filled nylon," and the glass fibers typically comprise 10-30% by weight. Like Cordura, glass-filled nylon is not used as a ballistic material in its own right, but is very popular in tactical gear, such as helmet "rails," on account of its toughness.

Ordnance velocity range

From 500 to 2000 meters per second, or roughly 1650 to 6500 feet per second. Small arms projectiles generally find themselves on the low end of the range — from under 500 to 1000 meters per second, or under 1650 to 3350 feet per second — whereas artillery fragments and tank main gun projectiles tend to travel at the higher end of the range. At this velocity range, as opposed to the hypervelocity range, impact dynamics are "classical" — that is, projectiles don't liquefy or explode upon impact.

Oxide

Ceramic material where a metal or metalloid is combined with oxygen. Aluminun oxide, Al_2O_3, is by a wide margin the most industrially and militarily important ceramic material. Zirconia, ZrO_2, is another noteworthy oxide ceramic, frequently used in biomedical implants and industrial machinery on account of its combination of chemical stability, great toughness, and good wear and abrasion resistance. Zirconia-toughened alumina, ZTA, is a compound derived from the combination of alumina with zirconia, and has intermediate mechanical properties. Magnesium aluminate spinel is a ternary oxide which performs extremely well in transparent armor. Glass is a combination of amorphous oxide compounds. Many terrestrial rocks are ternary, quaternary, or complex oxides (see: complex carbide). Olivine, for instance, is complex: $(Mg,Fe)_2SiO_4$. Spessartine garnets are quaternary: $Mn_3Al_2Si_3O_{12}$. On account of their natural abundance here on Earth, oxide ceramics are sometimes called "natural ceramics," as opposed to carbides, nitrides, etc., which are all "synthetic."

Oxynitride

Solid solution or an intermediate phase in a binary system of nitride and oxide ceramics. ALON is an example of this class of materials, and one which sees fairly wide use in transparent armor. SiALON is an industrially useful oxynitride with no known armor applications as a standalone material, but which was used as a sintering aid for silicon carbide in "SiAlON-bonded SiC" from XeraCarb — an interesting material, introduced around 2012, which doesn't seem to have been embraced by industry and may not be commercially available at present.

Parametricism

Architectural and product design philosophy, spearheaded by Patrik Schumacher, which espouses the use of evolutionary algorithms in a holistic total-systems-design approach. The ultimate endpoint of parametricism is a ruthless, organic, "evolutionary autopilot" in product and systems design — in effect replacing much of the process (beyond the selection of initial parameters and various aesthetic value judgments) with computational intelligence. Of increasing relevance towards armor design, particularly when ballistic simulations are run as part of the design optimization process; this enables optimal solutions to be "found," without mimicking convention or copying established configurations. Adept is, to a substantial extent, a parametricist systems design firm.

Partial penetration ("PP")

The word "penetration" can here be misleading. In body armor testing, a "partial penetration" traditionally describes a condition where the threat has penetrated the ceramic strike face of the plate, but was caught and stopped by the armor plate backer. In other words, a "partial penetration" describes a test scenario where an armor plate stopped a projectile within the plate itself — rather than by, e.g., deflecting it or inducing it to ricochet — which ultimately means that it was a successful test, if you've built the armor to defeat that threat. This term is now sometimes misused, as tests upon steel plates — where there is no partial penetration, or indeed any penetration at all — are often marked "PP" if the plate stops the threat.

PASGT

Armor system first issued by the US Army in 1983. The PASGT system consisted of a helmet and a vest. The helmet was made of a rigid aramid-PBO Phenolic fiber reinforced plastic. Produced from 19 layers of a 1500 denier Kevlar 29 prepreg ballistic fabric in a 2×2 basket weave, the PASGT helmet was the first composite helmet and the first helmet to offer protection from handgun rounds. The vest, which represents the first use of aramid in a military body armor system, was made of 13 layers of 1500 denier Kevlar 29 aramid fabric, without any resin component. Despite their age, the PASGT helmet and vest are still in use today — in Army Reserve and auxiliary units, and on Naval vessels.

Pearlite

Lamellar steel microstructure consisting of alternating bands of ductile ferrite and hard cementite. (Cementite is iron carbide, Fe_3C.) Nanostructured fully-pearlitic steels can attain yield strengths over 5000 MPa, and are therefore the strongest bulk (that is, non-fiber) materials on Earth — but they are difficult to produce, difficult to weld, can't attain very high hardnesses, and are strongly anisotropic, so they rarely see use in armor applications, where martensitic steels are by a wide margin more common. See also: bainite, martensite.

Penetrator

Hard bullet core used to improve performance against armor and hard targets. Typically housed within the jacket of FMJ ammunition — though not all FMJ rounds, and certainly not all bullets, contain penetrators. AP rounds often feature large penetrators made of tool steel or tungsten carbide based cermets. Recent military issue "ball rounds" such as the M855A1 and M80A1 feature exposed steel penetrators at their tips, for better hard target and anti-barrier performance. Penetrators are often optimized for hardness, mass, and sectional density.

Petaling

Ballistic penetration mechanism initiated by high tensile and compressive stresses. Petaling is the result of a process where the target material bends through ductile deformation upon initial impact, the tensile strength of the target material is exceeded, a star-shaped crack radiates from the site of impact, and the projectile, as it continues its penetration, pushes these V-shaped "petals" back. Petaling is most common when a high-diameter projectile of regular shape strikes a thin plate of a metal with a good combination of strength and ductility.

Pellet Armor

Ceramic composite armor where the strike face is comprised of discrete spherical or capsule-shaped pellets in a non-tessellated but nevertheless regular array. A derivation of mosaic armor. Pellet armor boasts better multi-hit performance than any other ceramic composite armor arrangement, but its single-shot performance-to-weight ratio suffers. It can be made flexible, to some extent. "LIBA" ("light improved ballistic armor") and "SMART" ("super multi-hit armor technology") are both very prominent examples of pellet armor. They have been widely used in combat vehicles — and, more rarely, in very high-performance body armor.

Plugging

Ballistic penetration mechanism in metal alloys where a cylindrical disc is sheared out of the target material and is ejected ahead of the projectile. There is generally little or no target deformation. Plugging is more commonly observed in harder alloys, and improving a material's hardness almost always increases its susceptibility to this failure mode; this is, in part, why RHA is far from the hardest or strongest grade of steel. Blunt-nosed and high-diameter projectiles are generally more likely to initiate plugging.   Adiabatic shear plugging is a variant of this failure mode where thermal stresses around the point of impact cannot be efficiently conducted away and weaken the target material in a characteristic manner.

Polycarbonate

Transparent amorphous polymer — lighter than glass, flexible, two hundred times more impact resistant, more clear than most glasses, generally without optical flaws, and easy to manufacture, even in very complex shapes. Widely popular in transparent armor systems, in sports equipment, in architectural and structural engineering, and in other applications almost beyond counting. A highly versatile and meritorious material.

Polycrystalline

A material comprised of numerous crystals of irregular size and shape. All common metals, the vast majority of ceramic materials, most natural stones, ice, and many common polymer plastics are polycrystalline.

Polycrystalline Diamond

Polycrystalline, ceramic-like, form of sp3-bonded carbon. Most natural diamonds of the sort used in jewelry are single-crystals, and transparent — in contrast, polycrystalline diamond is opaque, black, and usually totally synthetic. It is generally prepared by ”high pressure high temperature (HPHT) sintering,” which resembles the hot-pressing process for ceramic production, but which utilizes pressures that are orders of magnitude greater. For this reason, polycrystalline diamond is usually very expensive, and there are severe size and geometry limitations on dense parts. Curved tiles, for instance, are essentially impossible to produce at present, as are any tiles longer than 30mm to a side. Polycrystalline diamond is potentially of interest in armor applications due to its extreme hardness, twice that of boron carbide, and exceptional toughness, four times greater than boron carbide. Diamond aside, many other HPHT ceramic materials have yet to be explored.

Polymer

Chemical compound comprised of chains of small repeat units, typically of high overall molecular weight. Normally organic, in that carbon, hydrogen, oxygen, sulfur, and nitrogen constitute the basic building blocks — but inorganic Si-O polymers are also quite common, e.g. silicone. Though technically organic in at least that aforementioned sense, most polymers are wholly synthetic and are derived from petroleum. “Plastics” — such as polycarbonate and polypropylene — are solid, rigid organic polymers. Most rubbers and elastomers — such as polysulfide — are also organic polymers. Most adhesives and foams are also derived from organic polymers. Some polymer types are so versatile that they can be stiff plastics, or rubber-like elastomers, or adhesives, or foams; polyurethane falls into this category.

Polypropylene

Semi-crystalline polymer chemically related to polyethylene. In recent years, polypropylene fibers and tapes have been commercialized. The fibers are marketed under the trade-name Innegra S, and although their strength is ~75% lower than that of most UHMWPE fibers, their modulus is only ~50% lower — and their density is also substantially lower, at just 0.84 gm/cc. So, on a per-weight basis, the stiffness of polypropylene fibers compares very well with considerably more expensive UHMWPE. The tapes, which are commonly marketed under the trade-names Tegris and Curv, are typically sold as materials that resemble fiber composites. These tapes are reinforced with a matrix of lower melting point, unaligned and non-oriented polypropylene — in other words, they consist of fiberlike polypropylene tapes in a polypropylene matrix — and, for this reason, this class of material is often termed a “self-reinforced polypropylene composite.” These self-reinforced tape composites, like polypropylene fibers, are also relatively light and stiff, but exhibit a much lower tensile strength than most ballistic composite materials. Because of their very low density, high stiffness, and good toughness, they are popular in luggage and in sports equipment, and see some use as a trauma-reduction material in hard armor plates and soft armor panels. For instance: Teijin’s Twaron LFT-AT and AT-Flex fabrics are an aramid-Curv hybrid, and are intended for use on the body-side of soft armor panels, for BFD reduction.

Polysulfide

Family of elastomeric polymers characterized extensive bonding between sulfur atoms. Because polysulfides resist hydrocarbon absorption and are highly stable across a wide range of operating temperatures, their primary military use is as a sealant material for aircraft fuel tanks. The same polysulfide grades used as sealants are, however, also effective and exceptionally durable adhesives, and so see common use in armor plate construction. Polysulfides can be corrosive to steels and certain other metals on account of the high concentrations of elemental sulfur they contain. This unfortunate trait has limited their use.

Polyurea

Large family of elastomeric polymers characterized by repeating urea (NH2) 2 CO bonds between organic functional units. As it can be tough, rubbery, and resistant to chemical exposure and thermal shock, polyurea is commonly used as a coating for ceramic and steel hard armor plates. It is somewhat less frequently used as an adhesive in hard armor plate construction, or as a matrix material in fiber composites, though both uses are by no means uncommon.

Polyurethane

Large family of elastomeric polymers characterized by repeating divalent urethane bonds (–NH–(C=O)–O–) between organic functional units. Polyurethane is similar to polyurea in many respects, but is only rarely used as a coating material for armor plates. However, due to better toughness and better bonding characteristics, it is much more frequently used in the production of fiber composites and it is an extremely popular high-toughness adhesive.

Prepreg

Fabric pre-impregnated with a polymer resin and hardener, used to facilitate the production of fiber composite parts. Carbon fiber-epoxy and aramid-phenolic are common prepreg systems.

Protection coefficient

Method of determining the protective merit of an armor system against a given threat. Protection coefficient = V50 / areal density. Broadly applicable, but most frequently used to evaluate helmets and military-issue soft armor against the 17gr. FSP.

PS Ball

Refers to Soviet-era 7.62x39mm ball ammunition, which is extremely common worldwide, but exists in a vast range of varieties. Most rounds called "PS Ball," "Type PS," or "7.62x39mm ball" are 122 or 123-grain FMJ projectiles (~8 grams) with mild steel cores inside a copper jacket. But some are lead- cored, some have mild steel jackets, and there are various other possibilities. Muzzle velocities from an AK-47 are generally 2300-2450 fps. Various surrogates and stand-ins have been designed to replicate the “average” or “worst case” performance of the PS Ball — and, indeed, the NIJ apparently would like to use 7.62x39mm ball as an RF1-level threat in their forthcoming 0101.07 specification for ballistic armor, but it is unclear at this point whether they will use a surrogate projectile or will settle upon a foreign surplus round. (The published draft specification indicated a surrogate round, but

recent conversations with NIJ decision-makers and accredited testing centers strongly imply that they have found a foreign surplus round that they consider preferable. Time will tell.)

RCC

Like the FSP, a fragment-simulating projectile for ballistic testing purposes. The RCC is a regular cylinder of AISI 4340 steel, heat-treated to a hardness of 30 Rockwell C.

Reaction-bonded

Process where ceramic powder is mixed with sintering aids, compacted, and subsequently infiltrated with molten metal. The molten metal reacts with the ceramic powder and sintering aids, partially transforming into a ceramic itself, and a rigid cermet is formed upon cooling. The cheapest grades of boron carbide and silicon carbide are produced in this manner: Boron carbide or silicon carbide powder is mixed with carbon, pressed into a ceramic part with roughly 30% porosity, and infiltrated with molten silicon. Much, but not all, of the silicon reacts with the carbon to form SiC, and the result is a Si-SiC-B4C (RBB4C) or Si-SiC (RBSIC) composite. The smaller the volume fraction of unreacted silicon metal, the better the performance of the part, and the higher its hardness. At 3.0 – 3.13 gm/cc, reaction-bonded SiC cermets are generally lighter than sintered or hot-pressed SiC, because Si is substantially less dense than SiC; at roughly 2.65 gm/cc, reaction-bonded boron carbide cermet parts are generally denser than sintered or hot-pressed boron carbide, because of the SiC they contain.

RF1

Describes body armor that is built to comply with the forthcoming NIJ 0101.07 RF1 specification. In other words, describes armor that is built to comply with the NIJ 0101.07 RF1 draft proposal that has been circulating online. This should make for an armor plate that is rated to stop:

Three shots of 5.56x45mm M193 at 3250±30 feet per second
Three shots of 7.62x51mm M80 Ball at 2780±30 feet per second (See: “PS Ball.”)
Three shots of 7.62x39mm MSC Surrogate or foreign surplus at 2380±30 feet per second

Where each threat is tested on a different plate, and where backface deformation limits are unchanged from 0101.06 and set at 44mm. In essence, and if it takes effect in this form, the RF1 specification is an enhanced version of the NIJ’s 0101.06 “Level III” spec.

RF2

Describes body armor that is built to comply with the forthcoming NIJ 0101.07 RF2 specification. The RF2 specification, as of now, encompasses all RF1 threats, and adds the 5.56x45mm M855. So, ultimately, an RF2 rated plate should stop:

Three shots of 5.56x45mm M193 at 3250±30 feet per second.
Three shots of 7.62x51mm M80 Ball at 2780±30 feet per second.
Three shots of 7.62x39mm MSC surrogate or foreign surplus at 2380±30 feet per second.
Three shots of 5.56x45mm M855 at 3115±30 feet per second.

As with RF1, each threat is tested on a different plate, and backface deformation limits are set at 44mm. In essence, and if it takes effect in this form, the RF2 specification totally obviates the old "Level III+" rating-of-convenience, and RF2-rated plates should represent a fine armor option for most domestic and overseas/insurgency operations.

RF3

Describes body armor that is built to comply with the forthcoming NIJ 0101.07 RF3 specification. Whereas RF1 and RF2 are very different from the NIJ's old 0101.06 "Level III," RF3 is hardly different at all from the old "Level IV." A plate is RF3 compliant if it stops one shot of .30-06 APM2 at 2880±30 feet per second, and does not exceed 44mm BFD in so doing.

RHA, Rolled homogeneous armor

Tempered martensitic steel produced in vast bulk quantities for use in armored vehicles, where it is the standard grade of armor steel. Plates under 100mm thick are made in a low alloy steel similar to AISI 4130, are water quenched, and are subsequently tempered to a rather low tensile strength of 850 MPa. Plates over 100mm thick are made from a similar low alloy steel, though with the addition of nickel at roughly 1.5% by weight, which improves the through-hardenability of the steel — enabling the center of the thick slab to attain the same hardness as the surface. The term "rolled" refers to the fact that these plates are hot rolled rather than cast. The term "homogeneous" refers to the fact that these steels are of uniform hardness and martensitic microstructure, as opposed to being face-hardened, dual-hardness, multi-phase, or anything else along those lines. The typical hardness of an RHA plate is 350 HB, or 38 Rockwell C.

Russian Aramid

Sold under several trade-names, most commonly "AuTx," but also "Ruslan" and "Artec," the so-called "Russian aramids" are strong fibers and ballistic fabrics similar, *but emphatically not identical,* to the aramid fibers and fabrics used elsewhere. These Russian aramids, manufactured by a company called Kamenskvolkno, are copolymers (copolyamides) consisting of para-substituted phenylene and benzimidazole. The heterocyclic benzimidazole component makes the polymer chain asymmetrical, which keeps it from locking into a three-dimensional crystal structure, which in turn allows for greater draw ratios. Ultimately, this results in fibers which exhibit superior mechanical properties.

AuTx fibers, in particular, were compared to DuPont Kevlar KM2 fibers in a 2011 experiment performed by the US Army Research Labs. AuTx was found to be more than 40% stronger, 20% stiffer, and nearly 15% more elastic under strain than KM2. For these reasons, it should come as no surprise that AuTx ballistic fabrics exhibit a markedly superior performance-to-weight ratio. AuTx is indeed the best-performing "aramid" fiber known, and its performance is comparable to today's best UHMWPE materials. AuTx, Ruslan, and Artec ballistic materials are unfortunately rare in the USA, but are standard-issue in Russia, and are common in eastern and southern Europe.

S-Glass

Magnesium-aluminosilicate fiberglass. Markedly stronger, lighter, and tougher than E-glass — but weaker, heavier, and ultimately less effective than aramid and UHMWPE. Today, S-Glass is, like E-glass, very nearly obsolete as a body armor material — not used in body armor in any great quantity — but it still has various structural roles in military hardware. The "S" does indeed stand for "strength."

SAPI

"Small Arms Protective Insert" — the most common and widely-issued US Military hard armor plate. There are various different versions, and they can vary widely in the materials they use, in how those materials are arranged, and in their protective rating. All SAPI plates are ceramic composite, multi-curved, ICW, utilize monolithic ceramic strike faces, and are tested to military specifications rather than to NIJ specifications.

Sapphire

Single-crystal aluminum oxide, a typically transparent material most famous for its use as a precious stone in jewelry, but becoming increasingly popular in applications that require a water-clear, scratch-resistant material — e.g., in abrasion-resistant "glass" for smartphone screens and watch crystals. As its industrial production has been ramping-up to meet demand from the electronics sector, sapphire glass is also becoming increasingly popular in transparent armor applications, despite slightly higher density than, and slightly inferior performance to, ALON and spinel.

Sectional density

Measure of mass to area in the direction of travel. A long nail being hammered into a board has a very high sectional density; a flat dish of steel that you try to hammer into a board has a very low sectional density. The exceedingly simple equation generally used is Sd = g / mm2. So a 4 gram bullet with a diameter of 5.56mm has a sectional density of 0.129 g/mm2.   As a rule, AP projectiles are typically designed for high sectional density, for high sectional density always improves the anti-armor capabilities of a projectile. Tank gun AP projectiles take this to an extreme — they often fire WHA or DU "long rod" projectiles, with very thin, very long, *extremely* high sectional density penetrators. On the other hand, shrapnel from explosives or shells is often irregular in shape and can exhibit very low, almost dish-like, sectional density.

Shaped charge weapon

Generally, a heavy metal cylinder filled with an explosive chemical mixture, capped on one end with a thin, concave metal cone, usually of copper or a copper alloy. When the explosive detonates, that metal cone collapses and is propelled outwards in the shape of a narrow jet of material. The tip of the jet typically attains a velocity of roughly 8000 meters per second (26500 fps), though this depends on many factors such as explosive and jet geometry, the sonic velocity of the jet material, and the explosive load. When the extremely energetic and fast-moving jet hits a target material, that target material is pushed aside and penetration occurs with no change of mass in the target. Shaped charge weapons are highly effective against all known armor materials. Explosive reactive armor (ERA) evolved to counter this particular threat.

Shatter-Gap

A phenomenon in terminal ballistics. The shatter-gap describes a scenario where an article of armor has two V50 values — because, above a certain impact velocity, the armor is likely to shatter the projectile — whereas, below that velocity, the projectile core does not shatter and is therefore more likely to defeat the armor.   For a real-world example: A certain ceramic-composite armor system reliably defeats the .50 caliber APM2 at 2000 – 2400 feet per second, but is less likely to defeat that projectile at velocities over 2400 feet per second, and again less likely at velocities *under* 2000 feet per second. For, below 2000 feet per second, the projectile core is does not reliably fracture, and is much more likely to penetrate the armor plate as a solid body. In fact, the projectile was *most* likely to penetrate the armor at 1700 feet per second! The shatter-gap phenomenon has been observed in metallic and ceramic armor, but not in ballistic fabrics or composites derived solely from such fabrics.

Shatter-Gap Testing

A testing procedure to identify whether the shatter-gap phenomenon exists when testing a particular armor system against a particular threat. Very similar to V50 testing, but with additional testing at extra-low velocities to try and determine whether a second, lower V50 also exists. If it does, the armor system is usually assigned the lower V50 for purposes of compliance with ballistic standards and specifications.

Silica, SiO_2

Incredibly abundant compound derived from silicon and oxygen at a 1:2 atomic ratio. Exists in a huge variety of different crystalline structures, called polymorphs, of which the predominant natural forms are the various types of quartz. In these various forms, and as an impurity in other minerals, SiO_2 makes up more than 10% of the Earth's crust by both weight and volume. In daily life, SiO_2 is also commonly encountered in its unstructured amorphous form, as the main ingredient in glass. (Soda lime glass, the most common form of glass, is roughly 75% SiO_2, with the rest made up of other oxides such as Na_2O, CaO, and alumina.) Silica is of interest in armor for three reasons: First, as the primary ingredient in glass-ceramics and other glass materials used in transparent armor. Second, as the precursor to silicon carbide, which is wholly synthetic and Is made by reacting silica with a carbon source at very high temperatures. Lastly, silica is the major impurity in alumina; the common AD85 grade of alumina typically contains more than 10% silica by weight! Silica is also of considerable research interest, as its response to hypervelocity impacts seems anomalous in certain respects; unlike boron carbide, which performs anomalously poorly, silica performs better than one would otherwise expect, given its mechanical properties. This might imply that it undergoes a phase transformation at very high strain rates, perhaps rapidly densifying under extreme pressure to form the high-hardness, high-density stishovite polymorph.

Silicon Carbide, SiC

Synthetic ceramic compound derived from silicon and carbon at a 1:1 atomic ratio. With a low density of 3.2 gm/cc, good hardness and strength, and a highly stable diamond-like molecular and crystalline structure, silicon carbide is a relatively popular high-performance ceramic armor material, suitable for Level III plates, Level IV plates, and heavier vehicular and aerospace applications.

Density: 3.2 gm/cc
Hardness (Vickers): 2200-2800 HV1
Fracture toughness: 3 – 4 MPa · $m^{1/2}$
Compressive strength: ~3500 – 4900 MPa
Melting point: 2730°C

Simulation

The modeling of ballistic impact events *in silico*, using computer software such as LS-DYNA. Already highly accurate where metals and ceramics are concerned, and of increasing sophistication and relevance with respect to fiber-composite materials. Modern simulation techniques, though computationally demanding, can allow for hundreds or thousands of material configurations to be tested in series as part of an evolutionary, parametric total-systems-design process — which is a method developed and spearheaded by Adept.

Single-Curve

A plate curved on only one axis, much like a "∩". This simple curvature is typically denoted in terms of radius of curvature, e.g. "R400" or "R800." As the human torso is curved, single-curve plates are more comfortable to wear than flat armor plates — but they're not as comfortable as multi-curve plates, which have a complex, multi-axis curvature that more closely matches the human form.

Sintering

Process where ceramic powder is mixed with sintering aids, compacted to form a porous ceramic pre-form, and heated up in a furnace so as to fuse the ceramic particles together. While in the furnace, pressure is generally not applied, or is only applied in the form of pressurized gasses. (e.g., a pressurized nitrogen atmosphere makes it easily possible to sinter nitride ceramics.) Alumina is virtually always sintered in air. Silicon carbide is frequently sintered in a vacuum furnace or an argon atmosphere, but is more frequently offered in cheaper reaction-bonded form. Hot-pressed grades of silicon carbide are available, but expensive. Boron carbide has historically been unamenable to pressureless sintering, but new sintered grades are becoming available. Titanium diboride and many of the borides cannot, as yet, be sintered.
If the sintering temperature pushes one of the sintering aids past its melting point, so that it forms a viscous liquid that diffuses through the ceramic part and helps bind it together, this is called "liquid phase sintering." Though rarely essential, this can often simplify and facilitate ceramic part production, so it has become a very common method.

Sintering aids

Inorganic compounds or metals added as dopants to a ceramic powder, explicitly in order to assist in that powder's sintering process. Typically added at a concentration of less than 1% by weight. Sintering aids are either reactive — so initiate a series of chemical reactions during sintering that promote densification — or they have a lower melting point than the ceramic material they are added to, and form a liquid phase during sintering that functions much like a glue or binder. Magnesia, MgO, sees a great deal of use as a sintering aid in alumina ceramic part production. Calcium carbonate, $CaCO_3$, is another very common sintering aid in oxides and carbides.

SK

A reference to German ballistic test protocols and ratings, put forth in the document "Technische Richtlinie (TR) Ballistische Schutzwesten," developed and maintained exclusively by the German Federal Police. Similar to the German VPAM protocols in many respects, but with more aggressive contact-shot requirements and less military relevance.

Sloped armor

Armor positioned at an angle so that incoming projectiles are unlikely to strike a flat surface at a 0° angle of obliquity. A 100mm-thick sloped armor plate has a higher *effective* thickness than a 100mm-thick armor plate laid flat. Sloped armor also exerts asymmetrical forces on projectiles. This can either fracture projectiles due to shear stresses, or induce their ricochet — and, indeed, when projectiles strike metallic armor plates at a greater than 45° angle of obliquity, ricochets are highly likely; when they strike at a greater than 60° angle of obliquity, they're almost inevitable. The sloped armor concept has never been applied to body armor, but is common in heavy armored vehicles. The glacis and hull of the British Chieftain tank, and the turret of the Israeli Merkava tank, are classic, if rather extreme, examples of the implementation of sloped armor.

Small arms

Projectile weapons designed for individual use. Includes revolvers, self-loading pistols, assault rifles, main battle rifles, hunting rifles, sniper rifles, carbines, sub-machine guns, machine pistols, personal defense weapons, light machine guns, and anti-materiel rifles. Most small arms, with only rare exceptions, fire projectiles in the 4.6mm to 12.7mm caliber range. *Typical, average, and representative* velocities for standard ammunition loadings are 350 ± 100 m/s (1150 ± 325 fps) for handguns, and 850 ± 150 m/s (2795 ± 490 fps) for rifles. Hard body armor was developed to counter the rifle threat; soft body armor was initially developed to offer protection from fragmenting muntions, with the added benefit of protection from certain common handgun and submachine gun rounds.

Soft armor

Catchall term for laminate armor systems which are typically comprised of multiple layers of aramid fabrics, UHMWPE fabrics, or thin sheets of unidirectional aramid-resin or UHMWPE-resin composites. Soft armor is usually 4-9mm thick, weighs from 0.5 pounds per square foot to 1.2 pounds per square foot, and comes in the form of a "panel" wrapped in waterproof low-denier nylon. It is usually highly flexible. Soft armor is highly effective at stopping large-caliber and relatively low-velocity handgun rounds, and it is highly effective at stopping explosively-propelled fragments. Initially developed and issued to soldiers for purposes of protection from fragmenting munitions. As a rule, soft armor performs very poorly against rifle threats with high sectional densities and velocities, and it is almost completely ineffective against edged stabbing weapons, (1) because the sharp edge is capable of cutting or shearing UHMWPE and aramid fibers and fabrics, (2) because the knife threat has a very high effective sectional density and concentrates a lot of energy on a very small point, and (3) because fibrous materials and fiber composites are hardly capable of blunting or dulling well-made knives of hardened steel.

Soft body armor

See: Soft armor.

Solution phase sintering

Misnomer sometimes applied to, and indistinguishable from, liquid phase sintering. See entry for "sintering."

Sonic velocity

The speed of sound in a material or medium. Important in ballistics for various reasons, which include matching the impedance of materials in a composite, assisting in the estimation of the dwell phase subsequent to impact onto an article of ceramic composite armor, and because the maximum jet velocity of a shaped charge weapon is 2.41 times the speed of sound in the jet material.

Spaced armor

Armor that features one or more internal air-gaps between its strike face and any backing layers. Only used in vehicular armor, where the air-gaps may help to disrupt heavy kinetic energy projectiles and EFPs and reduce the risk of behind armor debris. As a rule, air-gaps are deleterious in body armor.

Spall

Small fragments that are ejected from an armor plate upon impact. Can refer to fragments from an armor plate's strike-face or its inner surface. In body armor, always the former; in armored vehicles, usually used to refer to behind-armor debris, e.g. in spall fracture.

Spall fracture

Ballistic penetration mechanism where the projectile doesn't penetrate the target, but produces secondary missiles that are ejected from the rear-face of the target. Also called behind-armor debris. Caused by fracture away from the impact point due to powerful pressure waves (see: impedance) traveling through the armor plate. Typically observed in thicker sections of strong materials, particularly when they're struck by highly potent kinetic energy threats, and particularly again when the armor materials exhibit laminated or dendritic microstructures.

Specific material property

The relation of a selected mechanical property to a material's density. Thus a material with a high *specific strength* has a favorable strength-to-weight ratio. To put it in concrete terms: RHA steel has a tensile strength of 1000MPa at a density of 7.8 gm/cc. A high-strength aluminum alloy has a tensile strength of 600 MPa at a density of 2.7 gm/cc. Although the RHA has a higher tensile strength, the aluminum has a much higher specific strength on account of its low density — and if the two materials were tested for strength *on an equal weight basis*, the steel would compare very poorly. The metals with the highest specific strengths are titanium alloys and certain ultra-high-strength steel alloys, such as bulk pearlitic steels. Advances in new high-strength, nanostructured aluminum and magnesium alloys may soon allow them to compete for one of the top two spots. The materials with the highest specific strengths, overall, are the high-strength "T" grades of carbon fiber, followed by M5 fibers.

All metals have similar *specific stiffness* values (see: modulus) with the exceptions of molybdenum and beryllium, which are superior. The high-modulus "M" grades of carbon fiber exhibit higher specific stiffness values than any other material.

Spectra-Shield

Trade-name for UHMWPE fibers and composite materials from Honeywell.

Spider silk

Natural fibrous protein derived from spider dragline silk. Presumably highly useful in the manufacture of soft armor and ballistic-resistant clothing, for although the best grades of natural spider silk are roughly 50% weaker than synthetic fibers such as UHMWPE and aramid, they are as much as 10x more flexible, elastic, and tenacious. A structurally complex "nanomaterial" in the truest sense of the word, spider silk is effectively impossible to synthesize via the means available to polymer chemists, and it is not presently used in any armor system. However, genetic engineering techniques — where silkworms are modified to produce spider silk instead of their normal silk — may soon make its production commercially viable, at which time it is sure to be tested extensively in various ballistic armor systems. Also of particular (and peculiar) interest is the fact that spider silk is made predominantly of the natural amino acids glycine and alanine — the same amino acids which are highly expressed in human skin and collagen — and indeed the application of spider silk to wounds and burns has been shown to promote and enhance healing.

Spinel

Ceramic material or mineral with the composition (A)(B2)O4 — where (A) and (B) typically have +2 and +3 charges, respectively. (In other words, A is a divalent metal or a complex mixture of divalent metals, such as magnesium, ferrous iron, zinc, manganese, cobalt, calcium, copper, barium, nickel, or strontium, and B is a trivalent metal, such as aluminium, ferric iron, or chromium.) There are hundreds of such compounds, but the most abundant natural spinels are the magnesium aluminate spinel, MgAl2O4, and the iron aluminate spinel FeAl2O4. The former is often just called "spinel," whereas the latter is known as the mineral hercynite. Magnesium aluminate spinel can be transparent even in polycrystalline form, and is sometimes, though infrequently, used in very high-end transparent armor systems. MgAl2O4 is, overall, the best-performing transparent armor ceramic; it consistently out-performs ALON, though ALON is the easier material to manufacture.

MgAl2O4
Density: 3.58 gm/cc
Hardness (Vickers): 1300-1600 HV1
Fracture toughness: 1.9 – 2.2 MPa*m^1/2
Compressive strength: 2000-3000 MPa

Steel

Alloy of iron, typically, though not always, with carbon as an essential component. Steel's mechanical properties are wholly dependent upon its microstructure, which itself is dependent upon the composition of the steel, as well as upon how the steel was produced, heat treated, and tempered. Relevant microstructural types for ballistic applications include martensite, bainite, and pearlite. Most of the steel alloys in military service are martensitic and are "low alloys," a term which means that they contain more than 95% iron by weight. This is not because low alloy steels perform better in ballistic applications, but because low alloy martensitic steels are easy to weld. Steel has been the world's most popular armor material for a couple thousand years now, and still retains that position, largely on account of its low cost, good toughness, and exceptionally good performance in integral armor (e.g. structural) roles. Steel is the best-studied and most well-understood of all metals; it can be optimized for strength, e.g. in certain grades of pearlite, in which case it can exhibit a specific strength better than any other known metal, despite its relatively high density; it can be optimized for hardness, e.g. in certain grades of carbon-rich martensitic tool steel, in which case it can become harder than any other known metal alloy, and can approach levels of hardness that are more commonly observed in ceramics and amorphous materials; it can also be optimized for toughness, in which case it is the toughest of all metals. Even so, new discoveries in the science of steel metallurgy are being made all the time, the boundaries are constantly being pushed back, and steel armor evidently hasn't even come close to maximizing its potential as an armor material.

Strike Face

On a body armor plate, the surface of an armor plate that is worn away from the body and faces the incoming threat. On an armored vehicle, the portion of armor that faces the incoming threat. The term can also refer to the ceramic portion of a ceramic-composite armor plate.

Surrogate

In ballistic armor testing, a test projectile designed as a stand-in for a hard to obtain or excessively inconsistent threat. Some of the very first armor testing protocols utilized surrogates — in Vietnam-era ceramic armor testing protocols, tests were at first performed against the APM2, but the researchers performing those experiments noticed excessive data scatter which they attributed to the variable hardness of the APM2's core, so they quickly developed a 7.62mm surrogate AP round with more tightly controlled mechanical properties. Surrogates are also used when test projectiles are difficult to obtain, or when the threat has been poorly standardized. Along those lines, as 7.62x39mm ball rounds can vary wildly in composition and performance, the NIJ had considered utilizing a 7.62x39mm surrogate round in their forthcoming NIJ 0101.07 specification. This plan seems to have changed, as they have recently reported that they have found a consistent and reliable source of 7.62x39mm MSC ammunition.

Tantalum

Refractory metal that, at 16.69 gm/cc in pure form, is more than twice as dense as steel, and just as dense as some tungsten heavy alloys. Unlike tungsten, tantalum is highly ductile and is frequently used in nearly-pure form. In the mid 20th-century, many experiments in tantalum-based AP projectiles and tantalum-based ordnance were performed. It was ultimately determined that, in projectile cores, tantalum and its alloys perform better than steel, though at much higher cost, and do not perform as well as WC-Co, tungsten heavy alloy, or depleted uranium — so it has not been widely utilized in small arms projectiles, nor has it been much studied or evaluated to that end, in the years and decades since. However, on account of its extraordinary combination of density, availability, and ductility, tantalum performs extremely well as a liner in shaped charge weapons and EFPs, a role it continues to fill to this day. Tantalum is also highly stable, inert, and non-reactive — even more so than most "noble metals," and it maintains this characteristic even at very high temperatures. For this reason, tantalum foil is frequently used as a liner in sintering furnaces and other articles of metallurgical and ceramic industrial production.

Technora

Ostensibly a trade-name for aramid and aramid-composite materials from Teijin. But, like the Russian aramids, Technora is chemically distinct from common grades of para-aramid — it is, in fact, a *related but distinct* copolymer. Whereas regular para-aramid is an alternating copolymer made of terephthaloyl chloride (TPA) and 3,4′-diaminodiphenyl ether (DPE), technora is prepared from TPA with a 50:50 molar ratio of DPE with p-phenylene diamine (PPD). Again like the Russian aramids, and plausibly for much the same reasons, Technora's properties are superior to those of common aramid, overall. It exhibits a lower density, together with good elongation and tenacity, and superior performance at temperature extremes. Much like Vectran, Technora's unusual properties aren't especially useful in ballistic applications, and it is much more expensive than common aramid, so, for these reasons, it is rarely used in armor. It is typically utilized in industrial and aerospace equipment — particularly in parts designed for service at temperature extremes.

Terminal ballistics

Branch of ballistics that deals with the projectile-target interaction: Projectile effects on soft tissue, armor penetration, kinetic energy transfer, momentum transfer, incendiary effects, shatter-gap, wounding potential, etc. The study of armor is the study of a subset of problems in terminal ballistics.

Ternary compound

Inorganic material — ceramic, intermetallic, or mineral — comprised of three elemental constituents. Magnesium aluminate spinel ($MgAl_2O_4$), magnesium aluminum boride ($MgAlB_{14}$), and aluminum borocarbide ($AlB_{12}C_2$) are somewhat relevant towards armor applications, though ternary ceramics are generally quite obscure and the vast majority have not been extensively studied. Quaternary compounds contain four elemental constituents, and are still more obscure.

Thermoplastic

Polymer that softens upon heating and hardens upon cooling. While soft, bulk thermoplastic parts can be molded or extruded. Polyethylene and nylon are both thermoplastic in nature, but heating thermoplastic polymer fibers such as UHMWPE can irreversibly degrade them.

Thermoset

Polymer that, once cured by heat or a chemical reaction, does not soften when subsequent heat is applied. Most epoxies and polyurethanes fall into this category.

Titanium

Metal that, when alloyed, can exhibit a startlingly high strength-to-weight ratio. It has poor thermal properties, and is difficult and expensive to produce, so it is not abundantly common in armor or other military systems; steel and aluminum are usually preferred. But in certain niche applications that call for an extreme specific strength combined with extreme toughness, such as our titanium armor plate, titanium alloys are without question the optimal material.

Titanium diboride, TiB_2

Boride ceramic derived from the combination of titanium with boron. Titanium diboride exhibits superlative performance characteristics in ceramic armor systems, but is difficult and expensive to produce, and is therefore very rare. Its mechanical properties, particularly its fracture toughness and compressive strength, are extraordinary, and, with a melting point of 3230°C, it is the most refractory ceramic material used in armor.

Density: 4.5 gm/cc
Hardness (Vickers): 2400-2800 HV
Fracture toughness: 6.2 MPa*m^1/2
Compressive strength: 5700 MPa
Melting point: 3230°C

Tool steel

Hard, brittle, typically martensitic steel alloy, used primarily in wear and machining applications that place a premium on hardness, strength, dimensional stability, and heat tolerance as opposed to toughness and ductility. Often optimized for hardness at elevated temperatures, particularly in "high speed steels." Generally high-carbon, around 0.5 to 2.2 wt. % C, and rich in precipitated carbides. Hardness typically at 57 to 70 Rockwell C. Very frequently employed in AP bullet cores to great effect, but not used in armor on account of low toughness and subsequent susceptibility to the brittle fracture and spall fracture failure modes.

Tungsten carbide

Carbide ceramic derived from the combination of tungsten with carbon at a 1:1 atomic ratio. Tungsten carbide is exceptionally hard and, at 15.63 gm/cc, is much more dense than lead, making for projectiles with high sectional density. It is, however, difficult to sinter in pure form, so it is commonly utilized as a cermet or "cemented carbide" — that is, tungsten carbide powder is mixed with 5-15% cobalt powder prior to sintering. The cobalt acts as a binder or "cement," and the result is a cermet material that is slightly tougher than pure WC, *much* easier to employ in the manufacture of bullet cores, but takes slight penalties to density and hardness. The tungsten carbide cobalt cermet, typically called "WC-Co," is still quite hard at roughly 1600 HV and still quite dense at over 13 gm/cc.

WC-Co and pure tungsten carbide have been evaluated for use in armor, where they both perform better than any other ceramic material on a thickness basis — but because they are so dense, their performance on a *weight* basis is terrible, several times worse than silicon carbide, about five times worse than boron carbide, and even slightly worse than RHA. So they are only of interest in vehicular applications where severe space restrictions are present, and high space-efficiency is required.

Tungsten heavy alloy

Alloy of tungsten with nickel and iron or copper, generally of the composition 90W-7Ni-3Fe (90% tungsten, 7% nickel, 3% iron) or similar. Typically produced via powder-metallurgical sintering techniques. Highly dense at over 17 gm/cc, and reasonably strong and tough, but, at only 25 Rockwell C, not very hard. Poor hardness notwithstanding, WHA makes for projectiles with extremely high sectional densities and good penetration characteristics — but it is more expensive and far less common in small-arms projectiles than WC-Co cores. It is indeed *exceedingly* uncommon in small-arms projectiles. It is, however, much more common than WC-Co in armor-piercing tank gun ammunition.

Twaron

Trade-name for aramid and aramid-composite materials from Teijin. Globally, Twaron is the most popular aramid material by a fairly wide margin.

Ultra-high molecular weight polyethylene, UHMWPE

Fiber material drawn from the simple hydrocarbon polymer polyethelene (C2H4). UHMWPE offers an outstanding performance-to-weight ratio on account of the high strength and stiffness of the bond between its carbon atoms, combined with its very low specific gravity (0.96 gm/cc). UHMWPE-polyurethane fiber composites exhibit truly outstanding performance characteristics in armor systems, and have become the material of choice; they far exceed aramid and S-glass on a weight basis, on a thickness basis, and by every other measure. UHMWPE fiber composites also enable very lightweight hard armor plates — either as a standalone material for protection from rifle ball rounds with lead or mild steel cores, or as a backer for a ceramic tile in plates designed to stop AP rounds. UHMWPE fibers and fiber-composites begin to degrade at temperatures over 70°C (158°F) and are not intended for use at temperatures over 80 to 100°C (176 to 212 °F) — for this reason, aramid is still preferred in ballistic systems where extreme temperature exposure, or performance under high temperatures, is a requirement.

V0

"V-nought," also known as "critical penetration velocity." Statistical technique for evaluating the performance of an armor material or system. Against a given threat, the V0 is the the maximum velocity at which no penetration at all is expected. For instance, a Level IV/RF3 hard armor plate should have a V0 of over 2910 feet per second against the .30-06 M2 AP projectile.

V50

Most commonly-used statistical technique for evaluating the performance of an armor material or system. Against a given threat, the V50 is the the velocity at which the likelihood of penetration is exactly 50%. In other words, fifty percent of the impacting projectiles will penetrate the target and fifty percent of them will not, when the projectiles and the armor are both as near-identical as possible. A Level IV/RF3 hard armor plate, designed to reliably stop the .30-06 M2 AP projectile at 2880 ± 30 feet per second, will typically have a V50 of roughly 3050-3200 fps against that same projectile.

Vectran

Aromatic liquid crystal polymer fiber similar to aramid in molecular structure and density, and with close overall mechanical properties. Vectran has an unusual combination of moisture resistance, high strength, exceptional stability to temperature extremes, good vibration damping characteristics, outstanding cut resistance, and very good creep resistance. For these reasons, it is primarily used in applications that call for reliable performance in extreme conditions, and where cut resistance, vibration damping, and dimensional stability may be important — such as cables, yacht sailcloths, satellites, space stations, and Mars rovers. (Vectran has been utilized in just about every Mars rover ever launched, including the recent *Perseverance*.) Vectran's superior cut-resistance has made it a candidate material for next-generation space suit gloves. Its ballistic performance has not been thoroughly investigated, but appears to be comparable to aramid, overall. As aramid is the cheaper material by a very wide margin, and as Vectran's unique properties don't appear to be particularly useful in armor applications, Vectran has not found much of a market in ballistic products.

VPAM

German ballistic standards organization with a number of product testing protocols for body armor, helmets, and ballistic materials. Most of the armor sold in continental Europe is built and tested to VPAM specifications, and much of that armor is certified with the organization. Internationally, second in influence only to the NIJ.

WC-Co

Tungsten carbide-cobalt cermet, typically used in AP ammunition cores. See: Tungsten carbide.

WHA

See: Tungsten heavy alloy.

Yarn pull-out

Ballistic penetration mechanism in ballistic fabrics. Rare in fiber composites. Occurs when the ends of a ballistic fabric are not well-gripped, and impact forces pull the yarn out of the fabric mesh. Can result in perforation and failure even if the fibers that make up the fabric do not break.

Yaw

Angular deviation of the nose of the projectile away from the line of flight. In ballistic testing, yaw can be measured by high-speed optical means, by radar, or simply by placing a sheet of paper called a “yaw card” in front of the target and measuring the dimensions of the perforation in the card. Yawing bullets are held to be particularly damaging to soft tissue, on account of the fact that they are more likely to tumble or fragment upon impact, but their armor penetration capabilities are reduced.

Zirconia-toughened alumina, ZTA

Composite ceramic comprised of alumina with the addition of roughly 15% zirconia (ZrO_2) by weight. Conceptually, ZTA is much like a metal alloy: The addition of zirconia modifies the microstructure of alumina, so that what results is a material that is at once both substantially stronger and substantially tougher. But because it’s also substantially more dense, at 4.1 – 4.3 gm/cc, and because it’s also much more expensive, ZTA has not yet seen significant use in armor. It has been tested, with confusing results — at times performing much better than aluminum oxide, at other times not performing better at all. ZTA is, in any case, a very important industrial ceramic on account of its high toughness and relatively low cost, and is of increasing importance in biomedical and dental implants.

Zylon

Extremely strong “rigid rod” para-phenylene benzobisoxazole (PBO) fiber introduced by the Toyobo company of Osaka, Japan. 60% stronger than the best grades of aramid and much more stiff, Zylon was popular in soft armor systems from roughly 1998 through 2003. The Zylon soft armor vests sold back then were exceptionally thin and light; thinner and lighter than anything available as of this writing, in 2021. (Perhaps too thin and too light — people familiar with the matter claim that those vests were made without an adequate margin of safety, and, though such vests were frequently certified by the NIJ, certification was a far less demanding process back in those days.) But Zylon is as controversial as it is strong. Zylon-based armor seemed to exhibit performance degradation over time when exposed to humidity and heat, and this culminated in a 2003 shooting where two officers were shot and killed with a handgun while wearing Zylon vests. An investigation subsequently revealed that commercial Zylon fibers contained excess phosphoric acid in the fiber, and that, when combined with heat and humidity, this impurity would cause it to degrade more rapidly than other fibers such as aramid and UHWPE. Although Zylon stabilization is possible, the material is now subject to a hard ban, and the NIJ will not certify body armor products that contain Zylon. Toyobo still manufactures PBO fiber today, but not officially for body armor.