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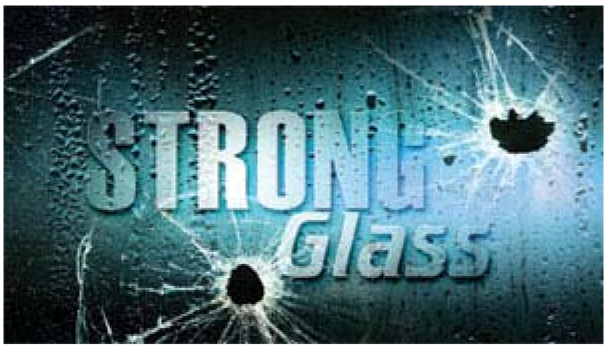
Strong Glass



Making transparent armor stronger and lighter. The original transparent armor consisted of several layers of glass held together in a frame. Later, glass layers were bonded together to form stronger laminates, an application still in widespread use today.

By Peter A. Buxbaum

Motorized vehicles have been used in warfare at least since the First World War. With that development came the need for transparent armor.

Transporting troops in jeeps and trucks would be far less practical if an enemy round, even a light round, were to luckily hit a vulnerable windshield putting the mission to an early and instant end. Even in heavily armored vehicles, drivers and shooters still need to see out and be protected from enemy fire.

The original transparent armor consisted of several layers of glass held together in a frame. Later, glass layers were bonded together to form stronger laminates, an application still in widespread use today.

More recently, glass has been bonded with plastics, acrylics and ceramics to form composites—laminations of dissimilar materials—which are stronger and lighter than glass. Ongoing research continues to seek stronger, but also lighter, transparent materials. Reducing weight from windows allows for an increase in payload weight. The transparent armor of the future will also be able to withstand a greater variety of ballistic threats. While some of these materials have been extensively tested in labs, a remaining challenge involves reducing production costs in order to make them commercially viable.

The importance of transparent armor has grown as the U.S. Army's requirements have advanced from minimizing the number of windows in a vehicle, noted Paul Slovick, vice president of engineering in the transparent armor division of Ibis Tek Inc. in Butler, Pa. Ibis Tek currently has transparent armor contracts with the Army as well as with military vehicle manufacturers.

“The glass is vulnerable and they were trying to avoid the replacement costs in case of damage,” Slovick explained. “It turned out that passengers in vehicles without windows tend to come up with motion sickness. You can’t transport troops to where they need to go and then not have them at 100 percent.”

Modern transparent armor has evolved from laminated glass to composite materials. Lamination refers to the permanent bonding of individual layers of materials such as glass into one piece. Composites are laminations of dissimilar materials, such as glass and plastic or glass and ceramics.

An all-glass laminated window would typically include layers of glass with interlayers of the resin polyvinyl butyric, or PVB. Single-material laminates of plastic polymers such as acrylics or polycarbonate have also been tried in ballistic windows, but haven’t worked as effectively as glass laminates or composites.

Polymers have the advantage over glass in that they do not fracture when hit. “Glass spiders upon impact,” noted Vic LaSala, vice president of research and development at American Defense Systems (ADS), Inc. in Hicksville, N.Y. “The polymer armor will grab the round and embed it without spreading damage.” ADS is working on several large contracts with Tank-automotive and Armament Command, the U.S. Navy, and the Marine Corps to design and manufacture protective systems for vehicles.

But at this point polymers by themselves can handle light rounds but can’t stand up to heavier fire. “Almost without doubt they need to be coupled with crystalline material or glass,” said LaSala

Further, the plastic laminates “don’t weather well and they mar fairly easily from wiper abrasion,” said Terry Jacobsen, an engineer at TransTech Products in Sylmar, Calif.

“They have been effective against handguns but not against rifle rounds. Their performance threshold is low as compared to all-glass laminates or composite laminates. Transparent composite laminates offer significant benefits over single material laminates.

The typical transparent armor composite includes four or more layers of glass and a plastic polycarbonate polymer. Some older military armor applications continue to use all-glass laminates, but newer applications consistently use composites. Advanced composites of glass and polycarbonate also have the advantage of using polyurethane bonding material at all layers, an advance over PVB.

“Polyurethane is recommended due to its much higher strength, higher temperature extreme tolerance, UV stability and better optical quality,” said Jacobsen. “PVB is not chemically compatible with polycarbonates. PVB yellows with age and has one-third the temperature performance range of polycarbonate or polyurethanes.”

Jacobsen considers composite materials to be today’s state of the art. “Composites have the advantage of being 40 percent to 60 percent lighter than equivalent protection level of all-glass armor,” he said. “Displacing glass yields weight reduction and reduces the cross-section of the structural member of the window.”

Future transparent armor composites are likely to include high strength polyurethanes, ceramics and crystalline materials such as artificial sapphire. Ceramics are already in use in limited numbers of military applications, according to military and industry sources, none which can be discussed publicly.

“Crystalline materials have the advantage of being very, very hard,” said LaSala. “That is generally what is needed to defeat armor piercing rounds.”

One ceramic material which has been much touted for its lightness and strength is called polycrystalline aluminum oxynitride, or ALON. ALON is a durable optical ceramic with a high degree of transparency from the ultraviolet through the mid-infrared wavelengths. Both ALON and sapphire enjoy high optical quality, low density, high strength, and high durability, according to materials provided by the Air Force Research Laboratory. Although industry and the military have been working on ALON for several years, production methods to make it commercially viable have yet to be perfected.

ALON’s high level of hardness has been reported to provide advanced ballistic impact resistance for safeguarding motor vehicle occupants. In testing, ALON demonstrated superior performance in single-hit impact testing and that the material can also withstand multiple impacts without penetration. As a result of these findings, engineers are evaluating it for possible insertion into ground-based transparent armor.

The Air Force is also looking at ALON for applications in rotary and fixed-wing aircraft.

“Our interest is in applications for windows as well as for shielding armament that are not enclosed,” said Bob Ondercin, program manager for transparencies at the Air Force Research Laboratory. “ALON has been laminated together with other materials to give high performance against high velocity threats. We are mainly interested in seeking protection from armor-piercing types of rounds. We also need to test ALON against lower velocity threats make sure material performs at low velocities as well.”

ALON’s main advantages are in reducing the weight of transparent armor materials, according to Ondercin. But Slovick noted that its production costs make it prohibitive for widespread application at this point.

“ALON and artificial sapphire have extremely good ballistic properties, but they are extremely expensive,” he said. “There are also size limitations with ceramics. You have to tile pieces together to make a front windshield. It would cost thousands of dollars to make a windshield and as soon as there is any degradation to the glass, even if it is a stone that gets kicked up, for all intents and purposes, the windshield would need to be replaced.”

LaSala commented on the enormous investment required to fabricate artificial sapphire. “It would take multimillions of dollars just to start up a factory to grow sapphire even on a limited basis,” he said. “There is also the difficulty in shaping these materials. It is relatively straightforward to manufacture flat plates but when you need curved materials it becomes even more difficult and more costly. Glass and polymers do not present the same degree of difficulty.”

Ondercin acknowledged ceramics are not “typically deployed at this point” and that “widespread use of ALON is probably two to five years off.”

Innovations in transparent armor are currently being employed in the Army’s tactical vehicle long-term armor strategy (LTAS). That three-tiered program seeks to build lighter and stronger transparent and opaque armor into vehicles as well as configure those vehicles for easy upgrades as advances in armoring materials come about.

Vehicles coming off the assembly line are outfitted with the LTAS A-kit, which includes armor—such as blast walls and plates—which would be difficult to add in the field because installing them would require disassembly of the vehicle. Those vehicles also incorporate mounting provisions and anchor points for the upgrading.

“As protection levels increase and armors evolve the B-kit armor would be applied to the vehicles,” said Jacobsen. “Vehicles become retrofitted as higher levels of armor become available.”

“Installing the upgrades thus becomes a bolt-on process,” added LaSala. “As new materials become viable and new armoring concepts materialize, the B-kit concept provides more flexibility.” The LTAS C-kit allows similar armor upgrading of the vehicle cab.

Replacements and upgrades for transparent armor are part of both the LTAS B-kit and C-kit, LaSala noted. “This may involve up-armoring existing machines and modifying machines as needed,” he said. “It may involve replacing laminated glass with strengthened glass and polycarbonate composites.”

Industry is heavily involved in the long-term armor solution, according to Slovick. “The whole purpose is to get everyone’s input how develop a vehicle that is lighter but that has all the protection capability that it needs,” he said. “Every pound saved on the vehicle is another pound that can be put toward the payload. We are trying to reduce the thickness, weight and density of transparent as well as opaque armor.”

Slovick expects that part of the job will be accomplished using so-called exotic materials such as new urethane compounds. “These have good ballistic properties and are already being used for low-velocity protection such as handgun protection,” he said. “Some parameters need to be incorporated in the new materials, however. For example, they need to be within the spectrum for night vision.”

“In general, we are always trying to upgrade our armor classifications to higher levels to be able to stop larger and more deadly rounds,” said LaSala. “The research is not static. We are always searching for the next increment in benefit to stop higher-level rounds.”

Future transparent armor materials will become either harder or softer, depending on the threat and application, noted Jacobsen. “New research going on is in thicker and harder polyurethanes that provide lower weights as protection levels increase,” he explained. “Exotic glasses made from sapphires are harder than today’s glass but is limited in production size and is very expensive.”

“Softer material will be required in some applications to absorb the impact energy better,” he continued. “Thick layers of urethane may defeat large chunks of debris and over pressures from IEDs but may not be effective against armor piercing bullets. The challenge is to accommodate a variety of threats for which different materials may be best suitable. One possibility involves fabricating panels which include glass exteriors and polycarbonate interiors. Polyurethane core plies may also be interchanged to limit the weight of the glass.”

For all of the research and technology involved in developing transparent armor, Jacobsen, for one, sees his work as a mission with a very important human dimension. “For every life that is saved with armor,” he said, “ten critical injuries are also prevented.”.