TRANSPARENT ARMOR

Sapphire transparent armor systems can reduce the areal density and thickness of traditional glass laminated systems without compromising ballistic performance.

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Traditional glass-only transparent armor systems can be quite thick and heavy due to the amount of glass needed to stop high-powered projectiles. These systems consist of laminated glass layers with a polymer backing to stop ballistic projectiles, which often consist of armor-piercing (AP) threats with a soft outer jacket and hard AP core. In glass systems, where thickness of individual glass layers ranges from 4 mm to 12 mm, the glass needs to absorb the energy from the projectile, and slow down the AP core enough for subsequent glass or backing layers to catch the core. As threats and specifications become tougher to defeat, ceramic composites are becoming a leading solution to reduce thickness and weight, while improving protection and transparency.

Saint-Gobain Crystals (ceramic materials) and Saint-Gobain Sully (glass-based armor lamination) initiated a co-development program to evaluate the effectiveness of sapphire sheets as a component of its Transparent Armor laminated system, Fig. 1. The outcome of this program was a complete laminated system, fully qualified with extensive ballistic testing on standard single-shot and multi-shot parameters, Fig. 2. As shown in Table 1, Sapphire Transparent Armor systems offer a thickness and weight savings of greater than 50%, and for certain systems the weight savings exceeds 60%.

An important feature of the Sapphire Transparent Armor systems is the ability of the sapphire to break apart the core of the AP projectile. This means that subsequent interlayers, glass, and backing materials need only defeat smaller, lower-energy projectiles. As shown in Fig. 3, when compared with that of glass, the Knoop hardness and fracture toughness of sapphire are far superior. These systems have been extensively tested, and partial results are provided in Table 2.

Optical properties

Unfortunately, most transparent armor systems frequently encounter harsh operating environments such as aircraft rotor wash or wind-blown sand. Fortunately, sapphire is extremely resistant to sand erosion and also is unaffected by exposure to chemicals and solvents, situations in which traditional glass-based systems would degrade and lose visible transmission. With a hardness of 9 on the Mohs scale (diamond is 10), sapphire is capable of withstanding harsh environments

Fig. 1 — These are CLASS^{300} and CLASS^{225} (Clear Large Aperture Sapphire Sheet) as grown (left) and after polishing (right).

Table 1 — Comparison of Saint-Gobain Sapphire Transparent Armor to glass armor

Threat	Number of shots	Glass thickness, mm	Glass areal density, kg/m²	Sapphire armor thickness, mm	Sapphire armor areal density, kg/m²	Thickness savings with sapphire armor	Weight savings with sapphire armor
7.62 x 39 API-BZ	3	58	133	20.78	55.6	64%	58%
7.62 x 54R B32 API	3	104	248	33.54	86.48	67%	65%

Table 2 — Sampling of ballistic tests of Saint-Gobain Sapphire Transparent Armor

ID number	Sample size, mm	Thickness, mm	Areal density, kg/m2	Projectile	Projectile velocity, m/s	Penetration
1	150 x 150	21.1	52.12	7.62 x 51 M-80 Ball	835	Partial
2	150 x 150	21.1	52.12	7.62 x 39 API-BZ	776	Partial
3	150 x 150	21.1	52.12	7.62 x 51 AP (M61)	768	Partial
4	150 x 150	21.1	52.12	7.62 x 51 AP (M61)	846	Complete
5	150 x 150	29.4	72.78	7.62 x 54R B32 API	857	Partial
6	150 x 150	24.87	67.46	7.62 x 54R B32 API	864	Partial
7	150 x 150	43.78	159.21	7.62 x 51 AP-WC	917	Partial
8	150 x 150	46.3	169.11	7.62 x 51 AP-WC	921	Partial

Fig. 2 — These images show the 7.62x54R B32 API hard projectile core before (left) and after impact (right) on sapphire strike face. Note the total destruction of the hard projectile core after contact with the Sapphire Transparent Armor system.

without transmission losses.

Sapphire Transparent Armor systems also utilize a novel interlayer material with industry-proven weathering durability under a variety of environmental conditions, and backing material that offers excellent scratch resistance, chemical resistance, and durability. The combination of an extremely durable sapphire strike face, non-yellowing interlayers, and durable backing layers, significantly reduces the need for maintenance/replacement, and allows for consistent high performance during service. Figure 4 shows the front panel of the Sapphire Transparent Armor system after being tested by the impact of four shots. Figure 5 shows the rear panel.

These materials also provide a luminous transmission that surpasses traditional glass-only systems, and excellent compatibility with night vision goggles. To illustrate its superior optical transmission, a Sapphire Transparent Armor System at 29.4 mm thickness that can defeat the 7.62x54R B32 round (Fig. 6) has a transmission greater than 85%, with haze levels around one percent, as shown in Table 3. For comparison, a typical glass window that could defeat the 7.62x54R B32 round in glass would have to be 55 mm thick with a luminous transmission of 73% and haze around 0.6%, showing the vast improvement in transmission provided by the sapphire system. Increasing the thickness of the system by adding additional glass layers to 41.1 mm thickness only slightly reduces the transmission to around 84%, with no change in haze.

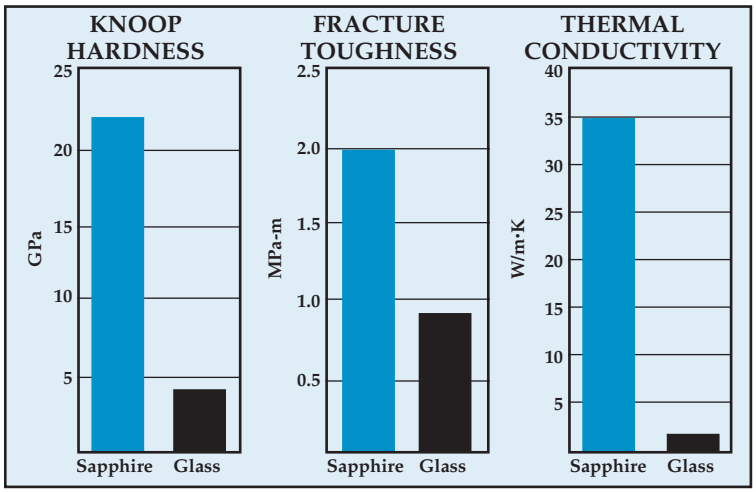

Fig. 3 — These graphs compare selected material properties of glass and sapphire. They show the superior properties of sapphire.

Engineering sapphire

Saint-Gobain Crystals, leveraging its different crystal growth technologies, provides sapphire in many sizes and shapes: tube, rod, and sheet. Most recently, Saint-Gobain Crystals has reinforced its leadership in very large sapphire sheet with the development and volume production of CLASS Sapphire (Clear Large Aperture Sapphire Sheet).

CLASS^{225} (225 mm wide x 660 mm long) and CLASS^{300} (300 mm wide x 508 mm long) sapphire are used as optical windows when strength, hardness (resistance to erosion), chemical inertness, and high optical transmission are a necessity. Those properties are also very beneficial for transparent armor, making sapphire an enabling solution for lightweight, high-performance transparent armor solutions

Table 3 — Optical measurements on Saint-Gobain Sapphire Transparent Armor System

Thickness, mm	Areal density, kg/m²	Luminous transmission, %	Haze, %
29.4	72.78	85.9	0.99
29.4	72.78	85.3	1.25
41.1	101.11	84.4	1.00
41.1	101.11	84.3	1.12

Fig. 4 — Front Panel, Sapphire Transparent Armor system (229mm x 330mm) is shown defeating four- shot multi-hit 7.62 x 39 API-BZ, Full STANAG Level 2. Full STANAG Level 2 Testing of four shots is considered difficult due to the spacing relative to shots #1 and #2, and #3 and #4.

Fig. 5 — The Rear Panel, Sapphire Transparent Armor system (229 mm x 330 mm) is shown defeating four- shot multi-hit 7.62 x 39 API-BZ, Full STANAG Level 2.

Dielectric coatings may be applied to block potentially lethal laser threats.

Fig. 6 — Sapphire Transparent Armor system (305 mm x 305 mm) is shown after defeating multi-hit 7.62 x 54R B32 API.

for both military and commercial applications.

Armor development programs are ongoing, and new designs are currently being tested against additional threat levels and environmental conditions. Additionally, Saint-Gobain Crystals has experience in providing Sapphire Electro-Optical and infrared windows with de-icing/defogging features, as well as dielectric anti-reflection coatings. The excellent thermal conductivity of sapphire is an added benefit when defogging capability is integrated into the systems.

Further, to protect those individuals on the friendly side of the windows, custom dielectric coatings can be applied to the sapphire to block specific wavelengths of interest, such as potentially lethal laser threats.

Saint-Gobain Crystals continues to develop the CLASS Sapphire, with the goal of producing sapphire sheet up to 400 mm wide. ⬣

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