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EFFECTUAL ANALYSIS OF CERAMICS ENGINEERING IN MILITARY AND DEFENSE APPLICATIONS

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ABSTRACT
Ceramics is having assorted applications in real life domains including military and defense which is the key focus in this manuscript. Ceramic plates (also known as trauma plates) are commonly used as inserts in soft ballistic vests. Most ceramic plates used in body armor provide National Institute of Justice Type III protection, allowing them to stop rifle bullets. A ceramic plate is usually slipped into the outer layer of a soft armor vest. A variety of ceramic materials are finding their way into military vehicles and other technologies. Engine components, missile radomes, and personal/vehicular armor are just a few of the applications. For the last half century, ceramics have been used for personnel and light vehicle protection against small arms and machine gun threats. Whether it is protecting Americans at home or abroad, ceramics are a key enabler for this mission.

Keywords: Ceramics, Ceramics in Defense, Ceramics in Military Applications

Introduction
The distinct characteristics of advanced ceramics, including light weight, the ability to withstand extremely high temperatures, hardness, resistance to wear and corrosion, low friction, and special electrical properties, offer major advantages over conventional materials such as plastics and metals [1]. Because of this, advanced ceramics are the foundation for the lightest, most durable body armor used for small to medium caliber protection available. Hot pressed boron carbide and silicon carbide ceramic is integrated with optimized composite structures to produce rugged multi-hit body armor plates.

Complete aircraft armor systems that include ceramic armor seats, components, and panel systems are found in the Apache, Gazelle, Super Puma, Super Cobra, Blackhawk, Chinook, and other military helicopters. Armor tiles are also specified in many fixed wing applications including the C-130 and C-17 aircraft [3]. Single, double and triple curve plates and multi-hit armor systems featuring boron carbide and silicon carbide advanced ceramics are also used for special operations forces as body, side and shoulder armor. Advanced protection for other vulnerable body areas including hips, legs and arms is under development.

The U.S. Army is developing metal-ceramic and metal-ceramic-composite hybrids for improved performance. The first type is metal-encapsulated ceramic armor that allows delay of ceramic failure for improved ballistic performance due to better metal-ceramic bonding. The second type, found on the Stryker-Interim Armored Vehicle, uses a polymer matrix composite to catch any spall off the back of the metal. Future applications for ceramic-based armor include the US Marine Corps Expeditionary Fighting Vehicle (formerly known as the Advanced Amphibious Assault Vehicle, or AAUV) and the US Army's Future Combat System [4].

Materials used in armor have come a long way since ancient times when hides and skins were first used to protect the body. For many years, armors were produced using various metals and alloys. In modern times, these metal suits have given way to armors made from super strong synthetic fibers and super strong synthetic hard materials. The latest super strong materials to be considered are ceramics.

Ceramic armor can be used to protect vehicles as well as individual personnel, and dates back to 1918. Ceramics are known to be some of the of the hardest materials, and unlike materials such as Kevlar (which uses its fibers to "catch" the bullet), ceramics break the bullet. The strongest and lightest ceramic is boron carbide.

Ceramic plates or trauma plates are used as inserts in soft ballistic vests. It is hard enough to ensure that a bullet or other weapon is deflected, meaning the armor material pushes out on the bullet with nearly the same force with which the bullet pushes in, thus preventing the armor from being penetrated. Ceramic plates provided to the U.S. military are called Enhanced Small Arms Protective Inserts (ESAPI) [5].

The downside to the use of ceramic is that it cannot sustain successive impacts without quickly losing some of its protective value. However, advanced ceramic technology has eliminated that problem by minimizing the size of the ceramic tiles to be as small as possible, with the matrix elements having a minimal practical thickness of about 1 in. (25 mm).

Materials Used in Ceramic Armor

The commercially manufactured ceramics for armor include materials such as boron carbide, aluminiumoxide, silicon carbide, titanium boride, aluminium nitride and Syndite (synthetic diamond composite). Boron carbide composites are primarily used for ceramic plates to protect against smaller projectiles, and are used in body armor and armored helicopters. Silicon carbide is primarily used to protect against larger projectiles.

Commercially, a variety of sintered, reaction-bonded and hot pressed ceramic materials are available, for example, Hexoloy® Silicon Carbide (SiC). Likewise common ceramic body armor components in the market are CeraShield™ High-Density Aluminum Oxides, CeraShield Silicon Carbides, and CeraShield Boron Carbides.

Mechanical Properties of Ceramic Armor

The mechanical properties of a few types of ceramic armors are displayed in the table below [6]:

Ceramic Armor	Compressive Strength @ RT (MPa x 10^6lb/in^2)	Modulus of Elasticity @RT (GPa x 10^6 b/in^2)	Poisson Ratio
Hexoloy®Sintered	3900 560	410 59	0.14
Saphikon®Sapphire	2000	435	0.27-0.30
Norbide®Hot Pressed	3900 560	440	0.18

Ceramic Armor	Grain Size (μm)	Density (g/cc)	Knoop Hardness (100g load)-Kg/mm^2	Fracture Toughness @ RT MPa xm$^{1/2}$x10^3 lb/in^2 /in $^{1/2}$
Hexoloy®Sintered	4-10	3.13	2800	4.60-4.20
Saphikon®Sapphire	N/A	3.97	2200	N/A
Norbide®Hot Pressed	8	2.51	2800	3.1

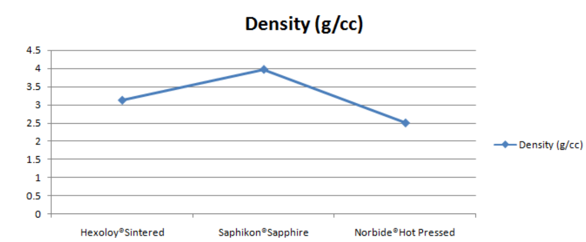

Figure 1. Density

Figure 2. Knoop Hardness

Applications of Ceramic Armor

The following are some of the key applications of ceramic armor:

- The ballistic protection applications of the ceramic armor include transport aircraft armor protection, land vehicles armor protection, AC-130U gunships armor protection, helicopter armor protection, and body armor (XSAPI, ESAPI, SAPI for military and police protection). For example Hexoloy-Silicon Carbide SiC specifically provides ballistic armor protection and bullet-resistant composite armor for military personal, vehicles, aircraft and police.
- Marine-grade ceramic armor for use in medium and small size boats.
- Protection for VIP vehicles

Benefits of Ceramic Armor

- The key benefits of a ceramic armor are listed below:
- Provides high performance armor protection
- High hardness and low weight
- Superior lightweight material for composite armor protection applications - a basic ceramic composite armor systems is approximately half the weight, of a similar steel-based systems (five times stronger than steel and 70% lighter)
- Controlled microstructures to ensure durability and performance
- Consistently reliable defense to unexpected threats
- Capable of defeating high velocity projectiles
- CeraShield™ ceramics when used along with an appropriate backing system, can overcome various threats including armor-piercing rounds and IEDs
- Design flexibility
- Excellent resistance to creep and stress rupture at temperatures up to 1650°C (3000°F).

Transparency Aspects

Figure 3. Transparent Ceramics

Because many ceramic materials are transparent to certain types of energy, light or otherwise, they can be used for infrared domes, sensor protection, and multi-spectral windows. In addition to these optical properties, such ceramics have the desired abrasion resistance, strength, and thermal stability. A special type of glass-ceramic material shows promise for electromagnetic windows for use in artillery projectile because of its suitable electrical properties and high temperature capability.

Silicon nitride (a non-oxide ceramic) is used as radomes for missiles in the latest air defense systems. It was specifically selected for missile radomes because of its mechanical strength and dielectric properties. The material allows microwave or other energy to pass through to locate incoming targets. Its mechanical strength allows the missile system to withstand erosion and large temperature excursions while flying at hyper-velocity through the atmosphere. Also under development are transparent infrared windows using nanocrystalline yttria (a type of oxide ceramic) for missile applications.

Improved glasses and glass ceramics are also being considered for armor windows with the desired ballistic performance. Glasses can be produced in large sizes with curved geometries, and can be produced to provide incremental ballistic performance at incremental cost. A fused silica glass is one material under development.

Other transparent materials are being considered for windshields, blast shields, and sensor protection in aircraft. A ceramic material called spinel (magnesium aluminate) has superior optical properties within the infrared region, which makes it attractive in sensor applications where effective communication is impacted by the protective dome's absorption characteristics.

Augmentation of Turbine Engine Efficiency

Figure 4. Ceramics in Helicopter Technology

Future Army helicopters will be able to fly farther and carry more payload thanks to ceramics. Turbine engine operational efficiencies can be increased through the use of ceramic matrix composites and ceramic thermal barrier coatings due to their high temperature capability. Ceramics have the potential to operate at temperatures above 1100 C with minimal or no cooling. Composites are also 30 to 50% lighter than the metallic alloys currently in use. When composite combustor liner and turbine vane applications are coated with ceramics, operating temperatures increase to 1650C and the components are protected from the combustion environment. A multi-component ceramic coating based on hafnium oxide has survived a 300 hour test at 1650C.

Ceramic Components for Security, Defense and Military Applications

As an ITAR class XVI and Export Controlled supplier, PFC manufactures Ceramic Components for Security, Defense and Military Applications. Since its founding, PFC has been delivering ceramic components to major Department of Defense and Department of Energy contractors, and during the last ten years has earned several development and manufacturing contracts for many DOD and DOE programs. PFC fabrication capabilities from developmental prototypes to production quantities had been at the core of gaining a good reputation with our customers. Our quality and price has increased our visibility and made us the first choice for many new design requirements.

Radar systems, test and equipment components, electronic surveillance, infrared systems, precise electromechanical devices utilize most advance ceramic material components fabricated at PFC.

Conclusion

The primary objective of the manuscript is to underline the applications of ceramic materials for military engineering and to guarantee precision in the reconnaissance and combatting of military targets as well as in safety and personal protection to preserve resources on the highest possible technical level. Against this background, machine, equipment and clothing components made of monolithic oxide and non-oxide ceramics as well as ceramic-plastic, ceramic-ceramic, and ceramic-metal composite systems are reliable and proven components in stationary and mobile marine and airborne applications today. For specific applications, they are also used in civilian sectors.

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