Industrial Ceramic Technology, Inc.

37 Enterprise Drive Ann Arbor MI 48103

Telephone (734)761-8137 Fax (734)996-0808

www.Indceramictech.com

Composite Structures for Ballistic Protection

Problem:

Lightweight hybrid composites that can offer substantial ballistic protection to tactical ground vehicles and, in turn, to military personnel are of ever-growing interest to the U.S. military. One of the major requirements for such a ballistic protection technology is the ability to defeat or protect against the 7.62mm NATO M80 ball round and 7.62mm NIJ IV or DIN C5-SF AP round threats. It is also an implicit requirement that such a technology be developed without any capital or operational cost penalties; rather, there be associated gains in operational efficiency and tactical performance during military action. Therefore, there is a need to develop armor systems that are based on high mass efficiency ballistic-shield materials, innovative and functional hybrid designs, and reliable & scaleable processing methods.

Conventional armor materials are typically made of steel, aluminum, or other hard metals. Although these metallic materials primarily perform a structural function, they provide reasonably good ballistic protection[1,2] at appropriate thicknesses (or areal densities). Often, this approach results in parasitic weight, which not only reduces fuel efficiency but also diminishes mobility in action. Recognizing that rapid deployment, enhanced fuel mileage, and reliable ballistic (and blast) protection are the keys to dominating future battles, new and innovative approaches involving lighter materials such as ceramics and polymers have become absolutely essential.

Several recent studies[3-9] have utilized monolithic ceramics such as Alumina (Al_2O_3), Boron Carbide (B_4C), Silicon Carbide (SiC), and Titanium Diboride (TiB_2) for developing personnel and vehicular ballistic protection armor systems. ***Owing to their low specific gravity, and high stiffness, hardness, strength and thermal stability, the ceramic-based systems have shown potential for improving upon current standards for ballistic performance, which includes multi-hit capability***.

However, cost issues and structural limitations have necessitated further research for newer and more advanced systems. Of late, ceramic-matrix composites (reinforced with whiskers or fibers) have emerged as the answer to the question surrounding the structural (toughness) issues of monolithic ceramics. Ceramic-based composites ranging from SiC (toughened)-Al_2O_3 to Siliconized-B_4C are being actively studied and touted for next-generation armor systems[1,3].

Approach:

One such SiC (whisker)-reinforced Al_2O_3 composite named CRYSTALOY ® is attractive for use as the hard front-face plate. Its desirable physical and mechanical properties are derived from the addition of discretely dispersed SiC whiskers in a matrix of ceramic powders. The degree of improvement in strength and fracture toughness obtained by whisker additions is substantial because the mechanism of micro-crack initiation, propagation and coalescence to critical crack size, leading to catastrophic failure, is significantly suppressed in whisker-reinforced ceramic composites[10-14]. Micro-crack initiation is suppressed as the whiskers pin the grain boundaries of the ceramic matrix and prevent grain-growth during processing at elevated temperatures which, in turn, results in high hardness and strength. Another benefit of the SiC whisker addition is to produce a strain redistribution effect which reduces stress at localized areas similar to the effect of stress redistribution due to ductility in a metal. Any deleterious localized

---

® Industrial Ceramic Technology, Ann Arbor, MI stresses are modulated in the presence of the whiskers, whereby, instead of a large and catastrophic crack, numerous small non-catastrophic cracks are formed.

Regardless of the nature of the ceramic-based front-face plate, it is now well established that a polymeric (Kevlar, Aramid, Fiberglass, or S2 Glass) or metallic backing plate is vital for overall ballistic shielding. The hard ceramic frontal plate performs the role of blunting the projectile and inducing a destructive shock wave on the projectile upon impact. The softer (polymeric or metallic) backing material acts as a 'catcher' for residual broken fragments in preventing target penetration. Virtually all of the kinetic energy of the projectile must be absorbed through deformation and failure of the fiber-reinforced composite laminate. The laminate also serves to provide physical integrity to the armor system and provide environmental protection. The dynamic response of the ceramic-polymeric composite armor system will be strongly influenced by the stiffness of the composite[6]. Ideally, the composite needs to be stiff enough to support the ceramic during impact, but compliant enough to allow high fiber strain and energy absorption during deformation by the projectile fragments.

Payoff:

Primary Military Applications

The proposed advanced, lightweight composite armor technology is primarily targeted for military ballistic (and blast) protection applications particularly in ground tactical vehicles such as Humvees and Jeeps, and in a variety of FMTV (Family of Medium Tactical Vehicles) and Security vehicles. With respect to the above tactical vehicles, the two major application areas are: (i) doors and cab-structure for protection against various assault rifle fires and (ii) roof and belly for protection against grenades, landmines etc.

If successfully developed and utilized in these critical application areas, the technology will not only offer superior ballistic protection but also result in weight savings (reduced areal density) compared to the conventional metallic armor. In terms of specific numbers, at an areal density of 15 lbs./ft^2 or less, the proposed hybrid-composite armor is expected to offer equal or better protection than the current steel armor with typical areal density of 17 lbs./ft^2. Moreover, in application, this reinforced composite armor can be used either as a replacement for existing armor or as an "add-on" (for which the reinforced-ceramic might be adequate by itself). In addition to mobile or moving-target protection, the proposed innovation could also finds its way into stationary applications – for protection of shelters, bunkers etc. against the 7.62mm type ballistic threats.

Other Possible Military and Law Enforcement Applications

The ballistic-shield or ceramic component of the armor system should also be amenable to fabrication into smaller and complex shapes, which carries it over to other military and law enforcement applications. Increased protection for ground troops is one of the potential areas of use for this armor system. Currently, there is a huge demand for "stand-alone" or "add-on" armor plates for additional chest and back protection.

Ballistic shield for machine gunners is another potential application for this system. The machine gunner is a critical component to an effective fire team due to his ability to lay down a large field of fire. Typically, the machine gunner and assistant gunner are targeted more by enemy fire as they pose a larger threat, are more exposed to operate the gun, less mobile and are harder to conceal due to tracer fire and muzzle flash. The proposed hybrid-armor system could be used as shield elements that may be quickly mounted/dismounted to machine guns (such as on the bipod legs for M60 and M249 machine guns) to provide additional protection to the gunner firing from short duration positions.

As with the military body armor, complex shapes of just the reinforced-ceramic or the hybrid-composite itself can be fabricated and used for added protection for law-enforcement personnel against 7.62mm and 5.56mm rifle fire than is currently available. More coverage is of key importance for law enforcement because their tactical encounters typically occur in more open areas with less cover.

In conclusion, the benefits of the proposed technology to the military are many. However, it would suffice to say that it could make the difference between "life and death" or "few lives versus many lives" or, ultimately, "a battle won instead of lost". Financially, the ramifications of successful use of this armor technology are huge because of what can be gained in terms of "saved lives" alone. Finally, it is also worth noting from the point of a market outlook that the armor industry is the one of the fastest growing areas involving structural ceramics with a growth rate of almost 15% in the last year alone.

References:

1. "Development and Current Status of Armor Ceramics," Viechnicki, D. et al., *Ceramic Bulletin*, **70**[6] pp.1035-1039 (1991).
2. "A New Family of Reaction Bonded Ceramics for Armor Applications," Aghajanian, M. K. et al., Pac.Rim. 4 pp.1–13 (2001).
3. "Alumina Ceramics for Ballistic Protection," Medvedovski, E., Am*. Ceram. Soc. Bull*, **81**[3] pp.27-32 (2002).
4. "Alumina Ceramics for Ballistic Protection," Medvedovski, E., Am*. Ceram. Soc. Bull*, **81**[4] pp.45-50 (2002).
5. "Army Focused Research Team on Functionally Graded Armor Composites," Chin Ernest, *Materials Science and Engineering*, **A259** pp.155-161 (1999).
6. "A New Approach for Improving Ballistic Performance of Composite Armor," Parameswaran, V., et al, *Experimental Mechanics*, **39**[2] pp.103-110 (1999).
7. "Complex Net-Shape Ceramic Components for Structural, Lithography Mirror and Armor Applications," Karandikar, P., Aghajanian, M., and Morgan, B., *Ceramic Engineering and Science Proceedings*, pp.561-567 (1994).
8. "A Brief History of Ceramic Armor Development," Skaggs, S. R., *Ceramic Engineering and Science Proceedings*, **24**[3] pp.337-349 (2003).
9. "Hardness/Toughness Relationship for SiC Armor," Ray, D. et al., *Ceramic Engineering and Science Proceedings*, **24**[3] pp.401-410 (2003).
10. "Fracture Resistance Behavior of Silicon Carbide Whisker-Reinforced Alumina Composites with Different Porosities," Krause, R. F. et al., *J. Am. Ceram. Soc.*, **73**[3] pp.559-66 (1990).
11. "R-Curve Measurement in Silicon Carbide Whisker-Reinforced Alumina Composites," Homeny J. and Vaughn W., *J. Am. Ceram. Soc.*, **73**[7] pp.2060-62 (1990).
12. "Toughening Behavior in Whisker-Reinforced Ceramic Matrix Composites," Becher, P. F. et al., *J. Am. Ceram. Soc.*, **71**[12] pp. 1050-61 (1988).
13. "Processing and Mechanical Properties of SiC-Whisker-Al_2O_3-Matrix Composites," *Am. Ceram. Soc. Bull*., **67**[2] pp. 333-38 (1987).
14. "Development of a Pressureless-Sintered SiC Monolith and Special-Shaped SiC(Whisker)- Reinforced SiC Matrix Composite for Lightweight Armor Application," Chu, H..S. et al, *Ceramic Engineering and Science Proceedings*, pp.359-364 (2003).