

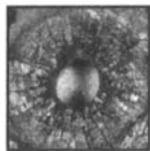
Ceramic Armor Materials by Design

Edited by

James W. McCauley
Andrew Crowson
William A. Gooch, Jr.
A.M. Rajendran
Stephan J. Bless
Kathryn V. Logan
Michael Normandia
Steven Wax

Ceramic
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Volume 134

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Proceedings of the Ceramic Armor Materials by Design Symposium held at the Pac Rim IV International Conference on Advanced Ceramics and Glass, November 4–8, 2001 in Wailea, Maui, Hawaii.

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COVER PHOTO: "Post-test photograph of impact of AP bullet against ceramic/aluminum target: (a) front view of ceramic element;" is courtesy of Charles E. Anderson Jr., and appears as figure 4a in his paper "Developing an Ultra-Lightweight Armor Concept," which begins on page 485.

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Contents

Preface xi

CERAMIC ARMOR DEVELOPMENT

An Overview of Ceramic Armor Applications 3

William A. Gooch Jr., U.S. Army Research Laboratory

**Armor Ceramics Under High-Velocity Impact of a
Medium-Caliber Long-Rod Penetrator. 23**

*Hans-Jürgen Ernst, Volker Wiesner, and Thomas Wolf,
French-German Research Institute of Saint-Louis (ISL)*

Practical Issues in Ceramic Armor Design 33

Bryn James, Defense Science and Technology Laboratories

**Ballistic Development of Tungsten Carbide Ceramics
for Armor Applications 45**

Pierre-François Peron, Etablissement Technique de Bourges

**Ballistic Development of U.S. High Density Tungsten
Carbide Ceramics 53**

*William A. Gooch and Matthew S. Burkins, U.S. Army Research
Laboratory; Richard Palicka, Cercom Incorporated*

Initial Tests on Ceramics in Composite Armor 63

W. Lanz, RUAG Land Systems

**Structure and Properties of Shock-Resistant Ceramics
Developed at the Institute for Problems in
Materials Science. 73**

*B.A. Galanov, O.N. Grigoriev, S.M. Ivanov, and
V.V. Kartuzov, National Academy of Sciences of Ukraine*

**Ceramic Armor with Submicron Alumina Against
Armor Piercing Projectiles. 83**

*E. Strassburger and B. Lexow, Fraunhofer-Institut für Kurzzeitdynamik
Ernst-Mach-Institut (EMI); A. Krell, Fraunhofer-Institut für Keramische
Technologien und Sinterwerkstoffe*

Armor Alumina Ceramics	91
<i>Eugene Medvedovski, Ceramic Protection Corporation</i>	
Ballistic Performance of Alumina Ceramic Armors	103
<i>Murat Vural and Zeki Erim, Istanbul Technical University;</i> <i>B.A. Konduk and A.H. Ucisik, Bogazici University</i>	
PENETRATION AND BALLISTIC TESTING	
An Overview of Ballistic Testing Methods of Ceramic Materials	113
<i>Michael J. Normandia and William A. Gooch, U.S. Army Research Laboratory</i>	
Theory and Experimental Test Methods for Evaluating Ceramic Armor Components	139
<i>Marc A. Adams, Jet Propulsion Laboratory</i>	
Long Rod Penetration of Ceramics	151
<i>D.L. Orphal, International Research Associates</i>	
Depth of Penetration Testing	165
<i>Bryn James, Defense Science and Technology Laboratories</i>	
Transition Between Interface Defeat and Penetration for a Given Combination of Projectile and Ceramic Material	173
<i>Patrik Lundberg, René Renström, and Lars Westerling, Swedish Defense Research Agency, FOI</i>	
SHOCK AND HIGH STRAIN RATE DYNAMIC	
Dynamic Fracture of Ceramics and CMC	185
<i>Albert S. Kobayashi, University of Washington</i>	
Compressive Fracture of Brittle Solids Under Shock-Wave Loading	197
<i>G. I. Kanel, Institute for High Energy Densities; S. J. Bless, The University of Texas at Austin</i>	
Recent Developments in Split Hopkinson Pressure Bar Testing	217
<i>W. Chen and B. Song, The University of Arizona; D. J. Frew and M. J. Forrestal, Sandia National Laboratories</i>	

Using Bar Impact to Determine Dynamic Properties of Ceramics	225
<i>Stephan J. Bless, The University of Texas at Austin</i>	
Shock Compression and Release Properties of Coors AD995 Alumina.	233
<i>William D. Reinhart and Lalit C. Chhabildas, Sandia National Laboratories; Dennis E. Grady, Applied Research Associates; and Tsutomu Mashimo, Kumamoto University</i>	
Compressibility and Shear Strength of Titanium Diboride Under Plane Shock Wave Loading	249
<i>D. P. Dandekar and E. J. Rapacki, U.S. Army Research Laboratory</i>	
Dynamic Indentation Damage of Ceramics	261
<i>Do Kyung Kim, Chul-Seung Lee, and Young-Gu Kim, Korea Advanced Institute of Science and Technology; Chang Wook Kim and Soon Nam Chang, Agency for Defense Development</i>	
Taylor-Impact Experiments for Brittle Ceramic Materials.	269
<i>L. C. Chhabildas and W. D. Reinhart, Sandia National Laboratories; D. P. Dandekar, U.S. Army Research Laboratory</i>	
ANALYTICAL AND COMPUTATIONAL MODELING	
Historical Perspective on Ceramic Materials Damage Models.	281
<i>A.M. Rajendran, U.S. Army Research Laboratory</i>	
A Comparison of Ceramic Material Models	299
<i>Douglas W. Templeton, U. S. Army Tank Automotive Research, Development, and Engineering Center; Timothy J. Holmquist, Network Computing Services Inc./Army HPC Research Center; Hubert W. Meyer Jr., David J. Grove, and Brian Leavy, U.S. Army Research Laboratory</i>	
Modeling Ceramic Dwell and Interface Defeat	309
<i>Timothy J. Holmquist and Gordon R. Johnson, Network CSI/Army High Performance Computing Research Center</i>	
3D Finite Element Analysis of Impact Damage in Metallic and Ceramic Targets.	317
<i>Fenghua Zhou and Jean-Francois Molinari, Johns Hopkins University</i>	

A Numerical Investigation of Microcracking Diffusion in Sandwiched Glass Plates	329
<i>Z. Chen and L. Shen, University of Missouri-Columbia; G.I. Kanel and S.V. Razorenov, Russian Academy of Sciences</i>	
Analytic Model for Penetration of Thick Ceramic Targets	337
<i>James D. Walker, Southwest Research Institute</i>	
Grain Level Analysis of Ceramic Microstructures Subjected to Impact Loading	349
<i>Pablo D. Zavattieri and Horacio D. Espinosa, Northwestern University</i>	
Analysis and Modeling of Ceramic Armor Penetration.	361
<i>S.J. Cimpoeu and R.L. Woodward, DSTO Aeronautical and Maritime Research Laboratory</i>	
Overview of the Rajendran-Grove Ceramic Failure Model . . .	371
<i>D. J. Grove and A. M. Rajendran, U. S. Army Research Laboratory</i>	
DAMAGE EVOLUTION AND MICROMECHANISMS	
Failure Phenomenology of Confined Ceramic Targets and Impacting Rods	385
<i>Donald A. Shockey and A.H. Marchand, SRI International; S.R. Skaggs, G.E. Cort, M.W. Burkett, and R. Parker, Los Alamos National Laboratory</i>	
Micro-Mechanisms of Compression Failure	403
<i>Sia Nemat-Nasser and Sai Sarva, University of California, San Diego</i>	
Damage Mitigation in Ceramics: Historical Developments and Future Directions in Army Research.	421
<i>D.M. Stepp, U.S. Army Research Office</i>	
Indentation Damage Behavior of Armor Ceramics.	429
<i>Do Kyung Kim and Chul-Seung Lee, Korea Advanced Institute of Science and Technology; Chang Wook Kim and Soon Nam Chang, Agency for Defense Development</i>	
Progress in the 3-D Visualization of Interior Ballistic Damage in Armor Ceramics	441
<i>Joseph M. Wells, Nevin L. Rupert, and William H. Green, U.S. Army Research Laboratory</i>	

PROCESSING AND MANUFACTURING

**An Assessment of Low Cost Manufacturing
Technology for Advanced Structural Ceramics
and Its Impact on Ceramic Armor 451**

Richard E. Tressler, *The Pennsylvania State University*

**High-Purity Submicron α -Al₂O₃ Armor Ceramics
Design, Manufacture, and Ballistic Performance 463**

Andreas Krell, *Fraunhofer Institut für Keramische Technologien und Sinterwerkstoffe (IKTS)*; Elmar Strassburger, *Fraunhofer Institut für Kurzzeitdynamik (EMI)*

**Solid Freeform Fabrication of Advanced Armor
Concepts: Opportunities for Design and Manufacture 473**

R.C. McCuiston, S.C. Danforth, M.J. Matthewson, and D.E. Niesz,
Rutgers, The State University of New Jersey

ULTRA-LIGHTWEIGHT AND NOVEL CONCEPTS

Developing an Ultra-Lightweight Armor Concept 485

Charles E. Anderson Jr., *Southwest Research Institute*

Ceramics That Exhibit a Threshold Strength 499

F. F. Lange, M.P. Rao, K. Hbaieb, and R.M. McMeeking,
University of California at Santa Barbara

Novel Ideas in Multi-Functional Ceramic Armor Design 511

Sia Nemat-Nasser, Sai Sarva, Jon B. Isaacs, and David W. Lischer,
University of California, San Diego

**A New Family of Reaction Bonded Ceramics for
Armor Applications 527**

M. K. Aghajanian, B. N. Morgan, J. R. Singh, *M Cubed Technologies, Inc.*;
J. Mears and R. A. Wolffe, *Simula Safety Systems, Inc.*

**Flexible Ceramic Coated Fiber Fabrics for
Lightweight Protection Systems 541**

Konstantin von Niessen and Rainer Gadow, *University of Stuttgart*

**Improved Performance of Alumina Ceramics with
Carbon Nanotube Reinforcement 551**

Michael Sennett, *Natick Soldier Center*; Sekyung Chang,
Robert H. Doremus, Richard W. Siegel, Pulickel M. Ajayan, and
Linda S. Schadler, *Rensselaer Polytechnic Institute*

Recent Progress on the Influence of Microstructure and Mechanical Properties on Ballistic Performance 557
J.C. LaSalvia, *U.S. Army Research Laboratory*

Transparent Armor

Transparent Armor Materials: Needs and Requirements 573
Parimal J. Patel and Gary A. Gilde, *U.S. Army Research Laboratory*

Microwave Reactive Sintering to Fully Transparent Aluminum Oxynitride (AlON) Ceramics 587
Dinesh Agrawal, Jiping Cheng, and Rustum Roy, *The Pennsylvania State University*

An Investigation of the Transmission Properties and Ballistic Performance of Hot Pressed Spinel. 595
Mark C.L. Patterson, *Technology Assessment & Transfer Inc.*; Don W. Roy, *Independent*; and Gary Gilde, *U.S. Army Research Laboratory*

Microstructure and Macrostructure Effects

The Effect of Microstructure on the Dynamic Behavior of Composite Alumina/Titanium Diboride 611
Kathryn V. Logan, *Georgia Institute of Technology*

Phase Equilibrium Studies in Al_2O_3 - TiB_2 623
Isabel K. Lloyd, *University of Maryland*; Kevin J. Doherty and Gary A. Gilde, *U.S. Army Research Laboratory*

Microstructure Development of Aluminum Oxide/Titanium Diboride Composites for Penetration Resistance 629
J.W. Adams, G.A. Gilde, and M. Burkins, *U.S. Army Research Laboratory*; L. Prokurat Franks, *U.S. Army Tank-Automotive and Armaments Command*

The Effect of Metal-Ceramic Bonding on Ballistic Impact. 635
Kevin J. Doherty, *U.S. Army Research Laboratory*

Aspects of Geometry Affecting the Ballistic Performance of Ceramic Targets. 643
I. M. Pickup, A. K. Barker, R. Chenari, and B. J. James, *Defense Science and Technology Laboratories*; V. Hohler, K. Weber, and R. Tham, *Faunhofer-Institut für Kurzzeitdynamik (EMI)*

Index 651

Preface

This volume contains the proceedings of the “Ceramic Armor Materials by Design” symposium held at the Pac Rim IV International Conference on Advanced Ceramics and Glasses held November 4–8, 2001 in Wailea, Maui, Hawaii.

In 1998, the Army formally approved a new basic research Strategic Research Objective (SRO)—“Armor Materials by Design”. This action resulted from a critical assessment of the survivability requirements of future lightweight weapon systems, as well as the emerging materials and mechanics science and engineering that could be brought to bear on this problem. It was concluded that there was a critical need for an integrated, multi-disciplinary basic research program that would result in the capability to actually design materials for passive, kinetic energy, armor applications.

Since some high performance structural ceramics have been shown to have outstanding armor properties at relatively low weight, the symposium was organized to address the ceramic armor aspects of the SRO. Researchers from around the world working in private industry, academia, and government organizations on passive transparent and opaque ceramic armor were invited to participate in this special program.

It was the goal of the symposium to connect ballistic performance to macro, micro, and crystallographic mechanisms of damage evolution as well as static and high strain rate mechanical properties and to assess the current status of computer codes to model and simulate the ballistic performance of these materials against kinetic energy projectiles. Current state-of-the-art research and development, as well as some historical content, was incorporated into an integrated program.

Most of the credit for this symposium goes to the organizing committee consisting of William A. Gooch Jr. and Michael Normandia, U.S. Army

Research Laboratory, Andrew Crowson, A. M. Rajendran, and David Stepp, Army Research Office of the Army Research Laboratory, Stephan J. Bless, University of Texas, and Steven Wax, Defense Advanced Research Projects Agency.

The symposium was co-sponsored by Steven Wax of the U. S. Defense Advanced Research Projects Agency, Andrew Crowson, A. M. Rajendran and David Stepp of the Army Research Office of the Army Research Laboratory, and William A. Gooch Jr. and James W. McCauley of the U. S. Army Research Laboratory. This support was critical to the success of the symposium.

Finally, thanks also go to Ms. Susan J. Burns, Battelle, Research Triangle Park, NC for her tremendous help with assembling this book.

James W. McCauley, Chair, Organizing Committee

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Ceramic Armor Development

AN OVERVIEW OF CERAMIC ARMOR APPLICATIONS

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ABSTRACT

The increasing capability of modern anti-armor threats and the need to field lower weight combat vehicles, capable of engaging an opponent with little preparation, have intensified the need for highly effective passive armor systems. Ceramic armor technology offers significant advantages for meeting future protection requirements, particularly for the U.S. Army's Future Combat System. The investigation and application of ceramics against small arms threats has a long history, dating back to the early 1960s and the ballistic performance of ceramic armors for personnel protection is very high; the principles governing these defeat mechanisms and the design parameters against such threats are now generally understood. However, achieving similar ceramic performance versus larger caliber, kinetic energy penetrator threats have long presented a difficult challenge. This paper presents an overview and discussion of the ballistic requirements, ceramic design factors and a chronology of significant U.S. developments and applications of ceramics for armor.

INTRODUCTION

The application of ceramics for armor continues to be primarily used in lightweight armor systems for protection against small arms and machine gun threats. The design of these systems is typically based upon the mechanical properties of the ceramic to fracture the penetrator and the ability of a rear compliant layer to catch the projectile debris and the damaged ceramic material. For defeat of these low-velocity, short projectiles, the fracture mechanism occurs very early in the process with the majority of the interaction time dedicated to energy conversion of the kinetic energy of the debris into deformation and delamination of compliant backing. For medium caliber and heavy armor applications, where the dominant threat is modern, high velocity, heavy metal eroding projectiles, the defeat mechanisms are much more complicated and of longer time duration. For the past three decades, a wide variety of research

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programs, both domestic and foreign, have focused on developing improved ceramic armor systems for the defeat of these threats. This paper presents an overview and discussion of the ballistic requirements, ceramic design factors and a chronology of significant developments and applications of ceramics for armor, with emphasis on research conducted on ceramic armors at the U.S. Army Research Laboratory (ARL).

TERMINAL BALLISTIC EFFECTS

A review of the difference in terminal ballistic effects observed during the interaction of different classes and caliber's of kinetic energy (KE) projectiles is important to understand the required defeat mechanisms and armor designs. The delineation between the threat projectiles is primary related to the caliber, velocity and energy available, but is not exact and some projectiles cross over into the two categories discussed below. While the penetrator/target interactions for these two categories involve similar processes, defeat of the higher performance, long rod threats require different emphasis in the armor design parameters to be successful and the progress has been much slower.

Small Arms/Heavy Machine Gun Defeat

Historically, ceramic composite armor systems were designed to defeat armorpiercing (AP), kinetic energy projectiles, mainly in the small arms and heavy machine gun category. These AP projectiles are purely inertial rounds, most commonly made of hard steel (HRc 60-64), of moderate density (7.85 g/cm³) with a few select rounds employing even harder tungsten carbide (WC) cores at higher densities (13.5-15.0 g/cm³). The hard core is generally encased in a thin jacket of a more ductile metal for interior ballistic or aerodynamic considerations, but penetration performance of the bullet is controlled by the core properties. Such projectiles typically have a length to diameter (L/D) ratio in the range of 3:1 to 5:1 with moderate muzzle velocities of less than 1 km/s. The generally accepted high-end caliber is 14.5-mm, typified by the Soviet KPV family of heavy machine guns. Some sabot, light armor-piercing (SLAP) rounds have velocities up to 1.3 km/s but with reduced core weight. Overall, these projectiles tend to produce a total KE on the order of 10³ - 10⁴ J.

Early Research [1-4] discovered that the perforation of ceramic armor systems occurred in three general stages: 1. shattering; 2. erosion; and 3. catching. During the shattering phase, the penetrator fractures and breaks on the surface of the ceramic plate; the high compressive strength of the ceramic overmatches the loading produced by the penetrator impact, and the penetrator material flows and shatters. This initial stage is followed by a period of damage accumulation in the ceramic material initiated by tensile wave reflections, and bending of the ceramic

tile and backing plate. During the second stage of ceramic armor penetration, the ceramic material is cracking, but the ceramic material can still contribute to defeat of the penetrator core through erosion mechanisms. In the final catching phase, the ceramic has lost considerable strength, but ceramic and backing combine to reduce the velocity through momentum transfer mechanisms.

The defeat mechanism for hard-core AP projectiles is primarily stages 1 and 3 with projectile fracture upon impact against an armor plate having sufficient hardness and/or high obliquity. The shattering and subsequent dispersion of the fragments result in a dissipation of the kinetic energy of the core over a larger area than if intact, thereby achieving defeat of the round with a reduced amount of armor plate. Monolithic ceramic plates were best suited to produce the shattering phenomena due to their high hardness and low densities. However, ceramic armor requires a backup component to support the ceramic and delay failure during the initial impact/shattering interaction; the backup component then serves to absorb the residual projectile fragments and comminuted ceramic particles (Phase 3). The state of the art in protection against small arms threats is typified in lightweight, two-component ceramic faced composite armors designed for use in breast plates for personnel body armor, armored helicopter seats and appliques to metal or composite based vehicle structures.

Heavy Metal Long Rod KE Projectile Defeat

The mechanism for defeat of long rod penetrators (LRP) is more complex than for the conventional AP projectiles described above. These penetrators are commonly made of high strength, high density materials, such as tungsten sintered alloy or depleted uranium, having densities near 18 g/cm³ with moderate hardness, good toughness and ductility; hence, the projectiles are not susceptible to shattering as hard core, relatively brittle, AP projectiles. This category includes APDS and armor-piercing, discarding-sabot, fin stabilized (APDSFS) projectiles, in calibers from 20-mm up to >140-mm. These LRPs are designed with a high L/D ratio (currently fielded examples exceed 30:1) and the high density core material coupled with relatively high muzzle velocity (1.3 - >1.6 km/s), yields KE in excess of 10⁶ J, creating a high energy density per unit area of target impacted than with a corresponding hard core AP round. These factors, when combined with the greater projectile length and reduced propensity for fracture, makes the LRP a much more effective penetrator. Even if the frontal portion of the LRP can be effectively damaged, a substantial portion of the rod remains to continue the armor penetration process. Thus, the conditions that allow a simple ceramic

composite to function effectively for small arms defeat do not apply when the armor is impacted by a LRP. The primary defeat mechanism is erosion (Phase 2) and the effectiveness is relatively low for simple ceramic armor systems.

SIGNIFICANT DEVELOPMENTS IN CERAMIC ARMOR TECHNOLOGY

Attempts to increase performance of ceramic tiles continued during the 1980's to present, as penetrator threats evolved. Researchers realized that increased efficiency of ceramics might be possible by lengthening the duration of the shattering stage of the penetration process, and/or by increasing the efficiency of the erosion process of the comminuted ceramic material. These researchers found that modest lateral confinement allowed constraint of the broken ceramic pieces, thereby enhancing the erosion phase of the ceramic penetration process. This confinement could be obtained by casting, as seen in the then very efficient armor developed in 1984-86 by ABEX-NORTON where silicon carbide tiles were inserted into very accurately cast aluminum matrices [5](Figure 1). Additional examples include test geometry's proposed by Woolsey and others [6,7] to provide a stiff and substantial confinement of the ceramic tiles in depth of penetration (DOP) configurations.



Figure 1. Abex-Norton Ceramic/ Metal Composite

The most significant observations during this period, however, were in 1987 by Hauver et al [8] who examined test geometry's that delayed the generation of damage in the ceramic tile, thereby increasing the duration of the shattering phase of the penetrator defeat process. As penetrator threats increased in length and L/D ratio, Hauver realized that the shattering stage duration was critical to the overall efficiency of the ceramic defeat process; he demonstrated ceramic tile confinement geometry's that substantially increased the shattering/erosion phase of the penetrator defeat process to completely erode the penetrator (Dwell). These experiments employed compressive confinement of the ceramic tile (heat shrink of the metal surround), in combination with techniques to delay tensile wave and bending damage to the ceramic. The ceramic performance was enhanced through control of system geometry to minimize damage and increase the shattering stage of penetrator defeat.

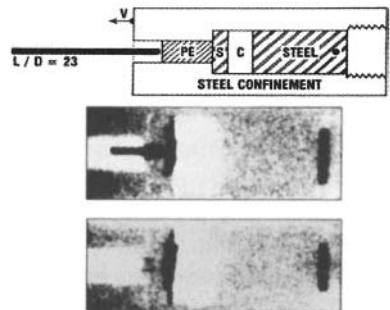


Figure 2. Hauver's Observation of Ceramic Dwell in Laboratory

However, the overall mass and space efficiencies of these laboratory packages were low, due to the considerable confinement materials employed in the geometry.

In 1994, research lead to the demonstration of a set of medium caliber and full-scale armor targets that incorporated existing ceramic defeat knowledge into an armor technology known as tandem ceramic armor (TCA) [9]. TCA determines the optimum performance of a specific cross-sectional ceramic armor design and then repeats the designs in multiple, shock-isolated sections; the performance is thus additive (Figure 3). Laboratory targets, utilizing conventional laminated ceramic-metal technology, demonstrated system designs that produced the state of the art for KE performance. A limiting factor, however, was the space requirements that grew as the penetrator performance increased.

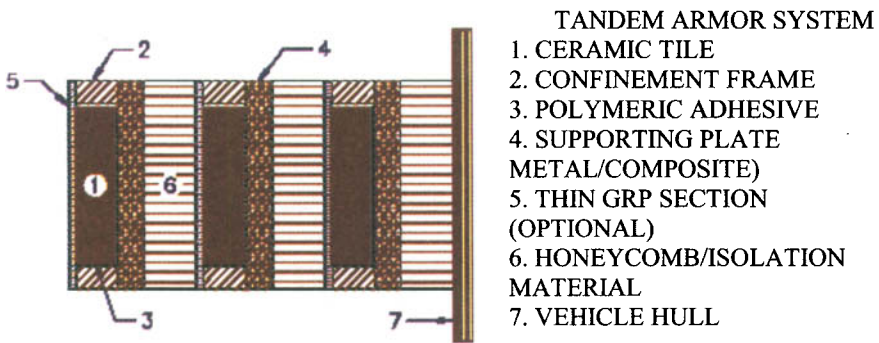


Figure 3. Tandem Ceramic Armor Concept

The latest efforts to generate increased efficiency in ceramic armors are to enhance both the erosion and “dwell” mechanisms of ceramic armor for penetrator defeat. The development of hot-isostaticpress (HIP) processing of ceramics with metal surrounds (Figure 4) has demonstrated dwell on the ceramic front surface of laboratory scale threats at efficient armor system areal densities [10]. This HIP processing forms a macro composite through the generation of residual compressive stresses (mismatch of thermal expansion coefficients of the ceramic tiles and metal confining plates) in

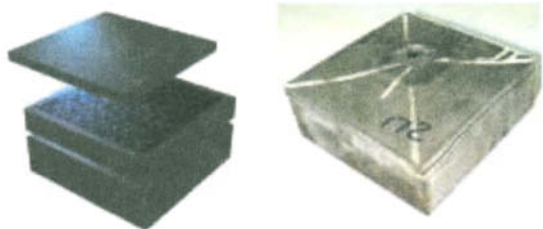


Figure 4. Hot-Isostatic Pressed Metal Encapsulated Ceramic

the ceramic tile during cool down of the HIP assembly from the pressing temperature. The macrocomposite is then able to withstand the large ballistic bending loads during round impact, so that the ceramic tile resists fracture and retains a high compressive strength. The macro-composite formed by HIP processing also keeps the broken ceramic pieces confined during the second erosive phase of the ceramic armor defeat process, should it occur, thus maintaining a high erosive efficiency.

CERAMIC ARMOR DESIGN REQUIREMENTS

As with all armor systems, many design factors and production decisions influence the effectiveness of ceramic armors. These processes have to be understood and controlled to maintain performance.

Ceramic Type

The technical ceramics available for armor are numerous, but generally are divided into the lower cost sintered and the higher cost hot-pressed ceramics. The higher cost ceramics are justified when the lowest areal weight system is the main requirement with the prime ceramics being boron carbide for body armor and airborne platforms and silicon carbide for ground vehicles. The high density tungsten carbide ceramic has specific applications where space is a limiting factor [11]. The lower cost sintered 99.5% aluminum oxide or silicon carbide or the reaction-bonded ceramics can be used were weight is not the driving requirement. However, for many armor applications, ultra-high hard steels, titanium or laminates of these materials with aluminum/composite backings are very competitive in performance with significant engineering advantages. Table 1 lists some of the primary producers of ceramics used today in armor applications.

Table 1. Current Ceramic Armor Producers

Ceramic Type	Producer/Type
Sintered	Coors CAP3 99.5% Alumina Morgan Matroc (UK) Alumina ETEC Alumina Ceradyne Sintered SiC Pure Carbon SiC
Reaction-Bonded	M-Cubed (Simula) SiC MC ² (Australia) SiC, B ₄ C
Metal Matrix Composite	Lanxide Dimox AS109 Lanxide Dimox-HT
Hot Pressed	Cercom B ₄ C, TiB ₂ , WC Ceradyne B ₄ C, TiB ₂ , SiC Saint-Gobain B ₄ C

Bonding/Impedance Effects: The use of hard face ceramic materials, bonded unto metal and composite backings, is typified in the classic work by Wilkens et al [12,13,14] on understanding the fundamental penetration mechanics that occur during the interaction of a hardcore steel projectile with a hard face aluminum oxide ceramic on aluminum. The primary applications involve bonding the ceramic to the metal or composite backing with lowdensity, low-impedance, and low shear strength adhesives. The unfavorable impedance effects and induced tensile failure across these boundaries and at the lateral boundaries of the ceramic are well documented by Hauver [15,16,17] for eroding long rod penetrators.

A less understood, but equally important effect from the use of a low-shear strength adhesive has been documented by a number of researchers. In 1993, Furlong et al [18] presented an exact solution for the transmission of spherical waves across planar surfaces; the coefficients of reflection and refraction were shown to depend not only on the acoustic impedance's of the media, but also on the boundary conditions at the interface, the wave face curvature, and the source frequency. Three types of boundaries can exist: 1) *free*, as with a free standing ceramic plate; 2) *no shear-coupling*, as with two unbonded or lightly bonded plates or 3) *shear-coupling*, where good adhesion or coupling exists, allowing the transmission of transverse motion and stress. The latter shear-coupled or no slip condition provides the best interface for a ceramic/metal armor design. Similar investigations were conducted by Alme [19]. Leighton et al [20] discussed the increased ballistic performance of laminated ceramic-titanium composites that resulted from increased interlayer bond strength (strong, shear-coupled metallurgical bonds). These effects are inherent in functionally gradient materials (FGM) composites as observed by Gooch et al [21] where metal layers transition into the ceramic layers without interfaces.

Adhesive Thickness and Uniformity: In simple bonded ceramic-metal laminates, an important factor to eliminate variability in ballistic performance is to maintain a uniform adhesive bonding layer at the minimum thickness. Burkins [22] modified the standard DOP test configuration by examining the ballistic results of a set of Taguchi experiments where the rear ceramic/metal bond thickness and lateral side confinement bond thickness were varied. The least variance occurred with a minimum bond thickness for the side and rear. For DOP tests, the maximum bond thickness allowed for the rear and sides is 0.127-mm (0.005 in). The uniformity of the bond thickness is maintained by placing spacers in the adhesive.

Confinement and Stiffness: The design of efficient ceramic systems begins by considering the mechanisms by which a ceramic tile fails during loading and designing the armor system to reduce the stresses contributing to early failure of the ceramic tile. Consideration of the ballistic event with emphasis on penetrator interface defeat on the ceramic front surface (Figure 5) lead Horwath [23] to determine two primary areas of concern: (1) the compressional loading of the ceramic directly under the penetrator rod, and (2) the maximum flexure of the ceramic plate and tensile stress/strain at the ceramic plate rear surface. These two factors are heavily influenced by the side and rear confinement thickness and materials.

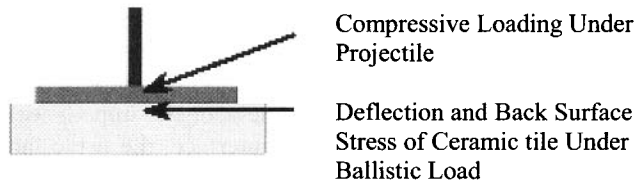


Figure 5. Primary Areas of Ceramic Tile

Multi-hit Requirements, Edge and Joint Impacts: As with all armor systems, the requirement to provide full protection against multiple impacts is still valid for ceramic armor designs. This requirement significantly impacts the design and tile size of ceramic designs. Table 2 lists the U.S. Army minimum impact spacing requirements for metals, metal laminates and ceramic laminates.

Table 2. Multi-hit Impact Requirements for Vehicular Armor

WEAPON CALIBER	METALS AND METAL LAMINATES* (mm)	CERAMIC LAMINATES* (mm)
7.62-mm	27	54
12.7-mm	45	90
14.5-mm	51	102
20-mm	70	140
23- to 25-mm	75	145
30- to 50-mm 152	76 (105)**	152

* Minimum spacing between impacts measured from center to center of impacts in vertical plane

** Full bore AP bullets only

The requirement to impact edges or joints and maintain the same ballistic performance as center tile impacts is a major design requirement for ceramic armor systems. Generally, ceramic design is driven by the edge or joint protection with the center providing greater protection. In some ceramic designs, the edges of the ceramic tiles are raised to increase the thickness to equalize the protection across the ceramic tile face. These factors result in increased areal weight for the design.

APPLICATIONS OF CERAMIC ARMOR FOR COMBAT VEHICLES

The application of ceramics as the main protection technology has made major advances in the last decade and represents the accepted technology, in use today, for small arms and heavy machine gun protection, primarily as a ceramic laminate applique over metal structural base armors and a few, newer composite based systems. A few systems were designed against 30-mm APDS, but few armored systems have been designed against larger threats. The following paragraphs describe some of the military armor applications in use or development today. These are representative, but not inclusive, of the myriad examples of ceramic armors under development worldwide. The information was provided by the fabricators and producers of the ceramics and products.

Armorworks

Armorworks Incorporated of Phoenix, AZ fabricates a wide range of ceramic composite products. Shown in Figure 6 is armored kit for an AH-60H helicopter floor. This armor system is an aluminum oxide based armor system that provides 7.62-mm APM2 protection at muzzle velocity. The armor kit consists of five panels, two of which are removable in flight (cargo hook access) and are nested in aft panel. The armor kit mounts on top of the floor panels using existing fastener points on the floor with coverage of about 5.1-m² (55-ft²). The armor panels passed MIL-STD-810E environmental testing including high and low temperature, solar radiation, sand and dust, salt fog, high pressure wash, humidity, fungus, vibration-resonance and vibration-endurance tests. The tile and backing are bonded; the gross panel shape is then fabricated by cutting and grinding and diamond saws and cores drills the holes to the final panel configuration.

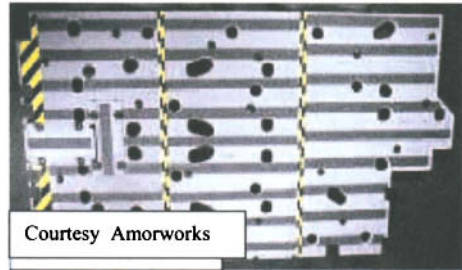


Figure 6. Armorworks AH-60H Floor Armor

Ceradyne Incorporated

Ceradyne Incorporated of Costa Mesa, CA develops and produces a wide range of advanced ceramics for many applications including ballistic grades such as hot-pressed boron carbide, silicon carbide and titanium diboride, pressureless sintered silicon carbide and reaction-bonded and sintered silicon nitride. Ceradyne has a long history of armor development beginning in the 1960's with the first applications of boron carbide for combat helicopter protection. Today, Ceradyne designs, develops and manufactures ceramic armor such as the ceramic breast plates and Cobra helicopter bucket seat of Figure 7.

Photos Courtesy of Ceradyne



Figure 7. Ceradyne Body Armor and Helicopter Seat

Cercom Incorporated

Cercom Incorporated of Vista, CA has been a prime producer of a wide range of commercial and ballistic grades of ceramics since 1985. Using their pressure-assisted densification (PAD) process, Cercom has hot-pressed large quantities of aluminum nitride, boron carbide, silicon carbide, silicon nitride, titanium diboride and tungsten carbide ballistic ceramics for the U.S. Army. Figure 8 shows Cercom ceramic tiles on the European Tiger helicopter seat and two different types of Cercom hotpressed boron carbide body armor inserts, a single-piece, compound curvature plate that is used in the U.S. Army Small Arms Protective Insert (SAPI) vest and two examples of multiple tiles fabricated into single protective inserts.



Photos Courtesy of Cercom

Figure 8. Cercom Ceramic Tiles for (L) Tiger Helicopter and (R) body armor inserts

German Ingenieurbüro Deisenroth

The German Company Ingenieurbüro Deisenroth (IBD) of Lohmar, Germany has established itself as a world leader in the variety and quantity of vehicles incorporating the MEXAS™ ceramic/metal/composite design; MEXAS™ stands for Modular, EXpandable Armor Systems and is composed of layered appliques that can be added to a basic vehicle structure to give the desired protection. While not conceptionally different from other appliques, the early use and continued application of this design is noteworthy and at least 39 different vehicles in ten countries utilize MEXAS™, including Austria, Switzerland, Germany, Canada, U.S., France, Italy, Finland, Sweden and Norway. Figure 9 provides a collage of the different vehicle types utilizing the MEXAS™ system, from engineer vehicles, tactical trucks, and numerous wheeled and tracked combat vehicles.

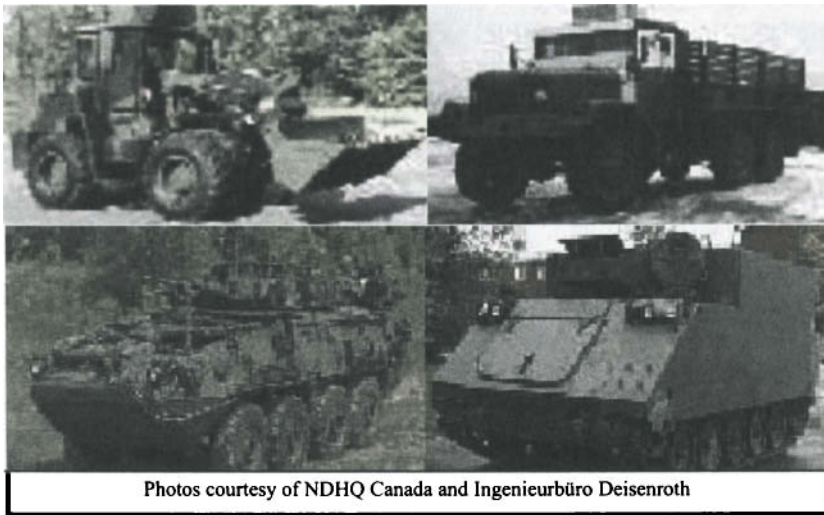


Figure 9. Examples of tactical and combat vehicles that mount IBD MEXAS™ armor

The design of the MEXAS™ system is shown in Figure 10 where a second layer of protection is being placed over the first. The vehicle structure provides the base protection and this system could be configured against three different missions or selective uparmoring of the vehicle. The panels are mounted by threaded attachment studs that accept special recessed fasteners.



Figure 10. Multiple layer concept of IBD MEXAS™ armor

Detroit Diesel General Motors of Canada

The Canadian National Defense Forces have been very active in providing increased protection for a wide range of tactical and support Canadian equipment. This requirement is driven by the deployment of their forces in a number of peace-keeping operations and the threat of increased small arms threats. Shown in Figure 11 is the Canadian LAV III Armored Personnel Carrier (APC) that has protection against small arms AP threats. The ceramic MEXAS™ composite armor is fabricated by the Canadian company DEW Engineering and Development Limited of Miramichi, New Brunswick, Canada under license to IBD. The characteristic mounting hardware of IBD armor is readily visible in the LAV III glasis area. DEW has supplied over 750 kits to the Canadian Defense Forces.



Photos Courtesy of Program Manager Brigade Combat Team

Figure 11. The MEXAS™ armor panels mounted on the Canadian LAV III APC

General Motors Defense Systems

The U.S. Army has initiated a major development program to transform the existing family of heavy vehicles to a lighter, more agile and deployable force. The Future Combat System (FCS) is planned for fielding by 2015. As part of the transformation, a contract to purchase an interim family of light vehicles under the Interim Brigade Combat Team has been awarded to GM GDLS Defense Group L.L.C. of Sterling Heights, MI [24]. Among the many variants is the Infantry Combat Vehicle (ICV) shown in Figure 12. Based on the LAV III chassis and hull, the ICV mounts a version of the MEXAS™ system of IBD. The similarities in the design and mounting are visible.



Photos Courtesy of Program Manager Brigade Combat Team

Figure 12. The ICV of the Interim Brigade Combat Team utilizes the IBD MEXAS™ applique

The GM GDLS contract indicates the ICV is to have overhead and all around protection for the squad and crew from 152-mm Artillery high explosive airburst at an undisclosed distance from and above the vehicle. The ICV shall also provide integral 360° and overhead squad and crew protection from 7.62-mm AP threats and 360° squad and crew protection from 14.5-mm AP ammunition, both fired from undisclosed impact conditions. The ICV shall also provide the capability to mount add on armor packages to protect against hand held shaped charge warheads up to and including the RPG-7.

Textron Marine and Land Systems

Textron Marine and Land Systems of New Orleans, LA is the prime fabricator for two interesting applications of ceramic composites, the U.S. Army Armored Security Vehicle (ASV) and the Marine Corp Landing Craft, Air Cushion (LCAC) vehicle (Figure 13). On the initial vehicle procurement, the ceramic composite armor kit on the ASV was produced by Simula Safety Systems of Phoenix, AZ, based on a MEXAS. license from IBD. Textron is currently working on a new composite armor design. The ASV offers front, rear and side

protection from 0.50-caliber armor-piercing ammunition. The LCAC is a high-speed, over-the-beach fully amphibious, landing craft capable of carrying a 60-75 ton payload. Critical areas of the vehicle including the turbine housings are also protected with a Simula-developed, aluminum oxide composite.

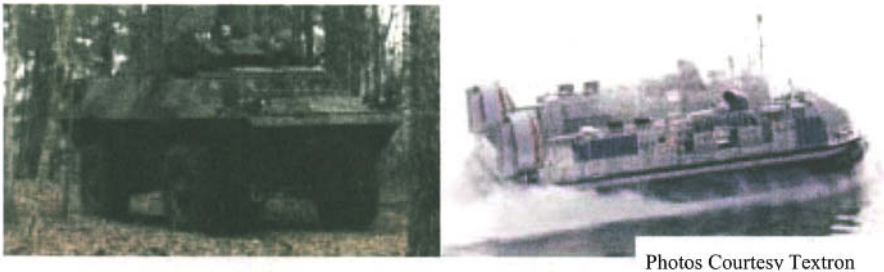


Figure 13. The Textron ASV and LCAC vehicles both mount composite armors

General Dynamics Land Systems

General Dynamics Land Systems Division (GDLS), Sterling Heights, MI has licensed and acquired an advanced, lightweight armor technology, named SURMAX™ Armor. This armor technology is used on the sides and rear of the hull and the sides of the turret of the U.S. Marine Corps' Advanced Amphibious Assault Vehicle (AAAV) to protect the vehicle from 14.5-mm AP threats and artillery fragments (Figure 14).

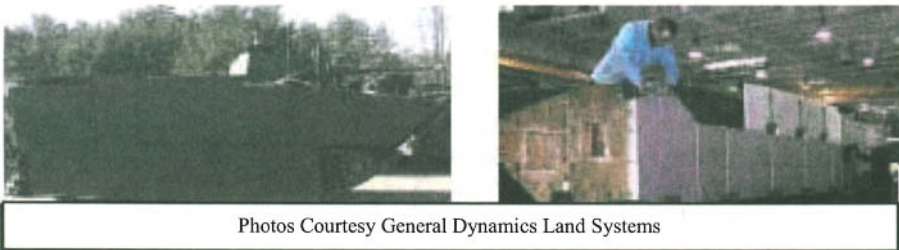


Figure 14. Marine Corp AAAV and SURMAX™ being mounted on AAAV spaceframe

SURMAX™ consists of a ceramic composite front panel attached to an armor backing. The backing can be a composite material (such as Kevlar or S-glass) or the structure of a vehicle (such as aluminum, steel, or titanium). The combination of the front panel and the backing are used to stop the penetrator and the application of SURMAX™ on the spaceframe structure of the AAAV is shown in Figure 14. SURMAX™ is also used on the U.S. Army's wheeled Armored