Development of Advanced Ceramic Armour systems for Personal Protection

Petru G. Lucuta
ACERAM Technologies

Scientific Authority: Guy Bergeron
DRDC Valcartier

ACERAM Technologies

Contractor Report

CR-2002-268

2002-12-18

REPRODUCTION QUALITY NOTICE

This document is the best quality available. The copy furnished to DRDCIM contained pages that may have the following quality problems:

: Pages smaller or Larger than normal

: Pages with background colour or light coloured printing

: Pages with small type or poor printing; and or

☒ Pages with continuous tone material or colour photographs

Due to various output media available these conditions may or may not cause poor legibility in the hardcopy output you receive.

☒ If this block is checked, the copy furnished to DRDCIM contained pages with colour printing, that when reproduced in Black and White, may change detail of the original copy.

Development of Advanced Ceramic Armour systems for Personal Protection

Petru G. Lucuta
ACERAM Technologies

Scientific Authority: Guy Bergeron
DRDC Valcartier

ACERAM Technologies

Contractor Report

CR-2002-268

2002-12-18

DIR W2207-00EV03/001/SV
October 26, 2002/ DIR –P-ff

TO:. Maj Mike Bodner, DLR 5
Gilles Pageau,
Guy Bergeron, DRDC Valcartier
DSTL2
DBDO 5

FROM: Petru G. Lucuta

CC: Lcol Jacques Levesgue
Ian J, Craigie
Daniel Bourget, DRDC Valcartier

SUBJECT: FINAL TECHNICAL REPORT

COMPANY: ACERAM Technologies Inc.
Telephone: (613) 549-7775 Fax: (613) 549-2345
E-mail: pglucuta@aceram.ca

TITLE: # DEVELOPMENT OF ADVANCED CERAMIC ARMOUR SYSTEMS FOR PERSONAL PROTECTION

DEVELOPMENT
OF ADVANCED CERAMIC ARMOUR SYSTEMS
FOR PERSONAL PROTECTION

EXECUTIVE SUMMARY

ACERAM Technologies in cooperation with DRDC Valcartier through an R&D project sponsored by the Defence Industrial Research (DIR) program have developed a new ultra-light advanced ceramic armour system – CERAMOR-MAP® (**CERA**mic ar**MOR** **M**odular **A**dvanced **P**rotection). The new system has been designed specifically for improved personal protection, but could be modified for use as add on armour on vehicles as well.

This report describes briefly the torso protection system consisting of a spall cover, CERAMOR chest plate, shock absorber and a commercial backing. The advancements reside in materials selection including the CERAMOR ceramic composite, the system components and their design. The new armour system is based on a tougher ceramic composite material (CERAMOR®) that provides closer than ever multi-hit capability, and a novel design approach to the ceramic components and the entire system. The advances in design are based on a dual role played by the ceramic by deflecting before defeating the projectiles.

Ballistic test results showing the ballistic limits for various levels of threats are also presented on NIJ Level III, Level IV Special and 12.7 mm APT C44 projectiles. CERAMOR-MAP® strike plates have proven to be resilient with excellent multi-hit at any level of threat. The two project objectives were satisfied for both 12.7 mm APT C44 and 0.30 cal AP M2 projectiles with protection systems of 50 kg/m^2 and 38.5 kg/m^2, respectively. In conclusion, the improved ballistic performance of the new Advanced Ceramic Armour System is outlined.

I. OBJECTIVES

The project aimed on the development of **a new ultra-light bullet resistant plate (BRP) for personal protection against 12.7 mm AP TC 44 projectiles at 500 m/s** at an overall areal density of 50 Kg/m^2. *The main objective stated above, **has been achieved** as new optimized prototypes of CERAMOR-MAP bullet resistant plates defeated the projectile at the desired speed.*

In order to reach its main goal, the project focused on

- A new lighter, tougher ceramic composite material based on titanium diboride–silicon nitride - SiAlON system; *This objective **has not been achieved as stated** because of the reaction occurring among the phases and consequently the desired properties were not reached. The **backup solution based on alumina two phases composite** was used, yielding the required properties for enhanced ballistic performance.*
- A novel design approach for components; *The objective has been achieved through a new patented design for the ceramic with the dual function of deflecting and defeating the projectile.*
- An advanced approach to design of the entire armour system to provide increased impact and ballistic resistance while further reducing the weight: ***The objective has been achieved** through advanced system architecture under word-wide patent protection.*

II. TECHNICAL ACIEVEMENTS:

This report summarizes the final results of the project with emphasis on achievements and ballistic performance of the new ultra-light CERAMOR®-MAP (**CERA**mic ar**MOR** **M**odular **A**dvanced **P**rotection) BRP (bullet resistant plate) developed to meet the main objective as well as outlines the challenges and technical disappointments encountered over the entire period.

II-a) CERAMOR SYSTEM for PERSONAL PROTECTION

A break-through for an advanced armor ceramic material was thought will first come from the development of a new class of structural ceramic composites based titanium diboride – silicon nitride - sialon system. The new TiB_2-Si_3N_4-SiAlON material did not work as reaction of the titanium diboride occurred.

The back up solution used an alumina based composite that yielded a hardness in excess of 20 GPa and a fracture toughness over 7 $MPam^{1/2}$ compared to 16 GPa hardness and 3 $MPam^{1/2}$ fracture toughness for typical alumina ceramics. The material provided improved performance and also yielded a lower specific weight. The scientific and technical innovations of this specific task resided in determining the compositional range and in tailoring the microstructure in order to produce the desired properties.

The microstructure/phase structure-properties relationship was used to tailor the properties of the material. The new material provided a ballistic performance equivalent to that of boron carbide at lower cost (a 30-40% cost reduction is seen as target) but should also provide an increased multi-hit performance, and enhanced damage resistance.

Secondly, a new approach in designing the whole armour system was undertaken in regard to the goal to further reduce the weight while increasing ballistic performance. The project focused equally on developments of a new interlayer between ceramic and backing, as well as improvements of the backing materials. The joining between the ceramic and backing has been improved and optimized. The overall areal density of the system was 50.0 kg/m^2 for the 12.7 mm AP TC 44 projectiles. Some work was also conducted on the spall cover that minimized front spall ejecta and increased impact damage resistance. For body armour applications, the backing was optimized to reduce behind-armour trauma, i.e., back-face deformation.

The new **CERAMOR®** MAP BRP developed over the period of the project is an advanced, ultra-light armour system for personal protection, based on a proprietary ceramic material formulation, patented ceramic design and advancements in components and system engineering and architecture. The entire system architecture and ceramic component design are protected by pending world wide patents. The systems provide enhanced advanced

protection through their unique features:

- ✓ Ceramic properties and system design tailored for rough handling, impact resistance and high endurance
- ✓ Complete protection for a given threat design against any level of threat projectiles
- ✓ Extreme multi-hit capabilities without bridge cracking or shattering of the ceramic
- ✓ Designed specifically for tungsten carbide penetrators
- ✓ Ultra light
- ✓ Expended for vehicles and other assets protection

The system comprises of:

- ➢ A polycarbonate **spall cover** on the strike face of the ceramic, confining the front of the ceramic and mitigating the spall
- ➢ **CERAMOR Ceramic** plate with nodes - MAP design is the core of the system with the role of deflecting and defeating the projectile. The nodes distribution is also disturbing the shock wave of the impact through anti-resonance reflections. As standard bullet resistant plate a flat surface ceramic strike plate was also produced and commercialized.
- ➢ A stiff polymer-carbon fibre composite of complex layers was designed as a **shock absorber** behind the ceramic with the role of displacing the energy conoid and confining the back of the ceramic, while mitigating the transition between ceramic and backing;
- ➢ **Degraded** (hybrid) commercial **backing** made of Kevlar, Titan-Kevlar, Spectra, Titan Spectra, Dynema, Titan-Zylon, usually a combination of two of these materials, few plies reinforced with carbon-fibre behind the shock absorber, with the role of catching the fragments (mainly ceramic) penetrating the shock absorber.

The whole CERAMOR®-MAP system has been designed based on the dual

functions concept of deflecting the armour piercing (AP) projectiles before defeating them. The projectile fragments are stopped by the shock absorber while the backing has the role to retain small ceramic fragments that cut through the shock absorber. As a result in weighting the system the emphasis is on the ceramic component, which has to perform its role for a given level of threat.

To date CERAMOR MAP system for personal protection developed through the project is under world-wide patent protection and it combines:

- *An effective novel spall cover*
- *A proprietary, new lighter, tougher ceramic composite material = CERAMOR based on alumina*
- *A new component design with nodes on the strike face,*
- *A proprietary shock absorber composite based on carbon fibers reinforcement, and*
- *An advance degraded backing.*

Overall, an advanced design of the entire BRP system to provide increased impact and ballistic resistance while further reducing the weight has been achieved through the project.

It was also found:

- ✓ There is a threshold thickness of the spall cover depending on the threat and required spall
- ✓ For improved ballistic performance, the ceramic requires high fracture toughness, hardness and tensile strength, besides a high sintered density
- ✓ There is a threshold of the areal density of the ceramic in relationship to the impact energy and the projectile (AP or not);
- ✓ Semispherical nodes of mono-size distribution were chosen, produced and tested
- ✓ The nodes size and spacing are related to the level of threat and the nodes proved to be more efficient for AP projectiles
- ✓ A new generation composite shock absorber was developed
- ✓ Improved backing based on commercially available materials was developed

✓ An overall light areal density BRP was designed for the different levels of threat.

The integration of the system components is done in an autoclave under controlled temperature and pressure to assure the optimum bonding of the components into the system. Figure 1 displays the front and back of an integrated CERAMOR-MAP strike plate that has been recently optimised.

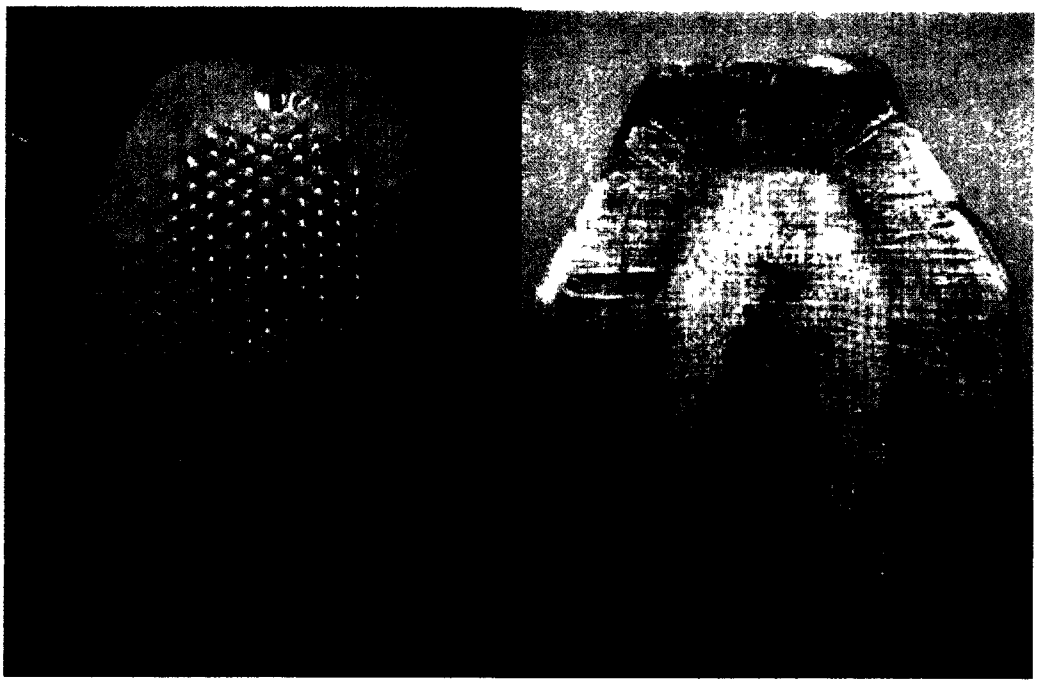

Figure 1. The front and the back of an integrated CERAMOR –MAP bullet resistant plate offering protection against 7.62 Bofors and 7.62 M2 AP projectiles. (front face on the left; back face on the right).

II-b). LEVEL of PROTECTION:

Through the duration of the project, bullet resistant plates for different levels of protection were design, tested and improved. For the Canadian plates of multi-curvature design with the overall area of 0.068 m^2 the following optimal physical characteristics were determined as follow:

- **<u>NIJ level III - stand alone plate</u>**

a) *CERAMOR-STANDARD* *2.3 Kg ~ areal density:* ***33.8 Kg/m^2***

b) *CERAMOR-MAP* *2.1 Kg ~ areal density:* ***30.9 Kg/m^2***

- **NIJ level IV special or STANAG 4569 level III - stand alone plate**

  a) *CERAMOR-MAP* *2.75 Kg ~ areal density:* ***40.4 Kg/m^2***

- **NIJ level IV special or STANAG 4569 level III - in conjunction with level II vest**

  a) *CERAMOR-MAP* *2.62 Kg ~ areal density:* ***38.5 Kg/m^2***

- **12.7 mm AP TC 44 Projectile at 500 m/s - stand alone plate**

  b) *CERAMOR-MAP* *3.40 Kg ~ areal density:* ***50.0 Kg/m^2***

The areal density of the CERAMOR plates is similar for high-level threat to that of boron carbide. The ceramic material characteristics provide a superior performance of the plates against armor piercing projectiles with tungsten carbide core.

II-c) BALLISTIC PERFORMANCE

Extensive ballistic testing was conducted using various projectiles and it was used to determine the threshold limits on the ceramic and backing for the system at a given level of threat. The ballistic testing was also used to establish multi-hit capability of the CERAMOR bullet resistant plate. Ballistic testing for the various level of threat were performed at Barrday Inc., Bosık Consultants, CGF Gallet and H.P. White Laboratories. The performance of the plates is exemplified for the different level of threat in the figures below:

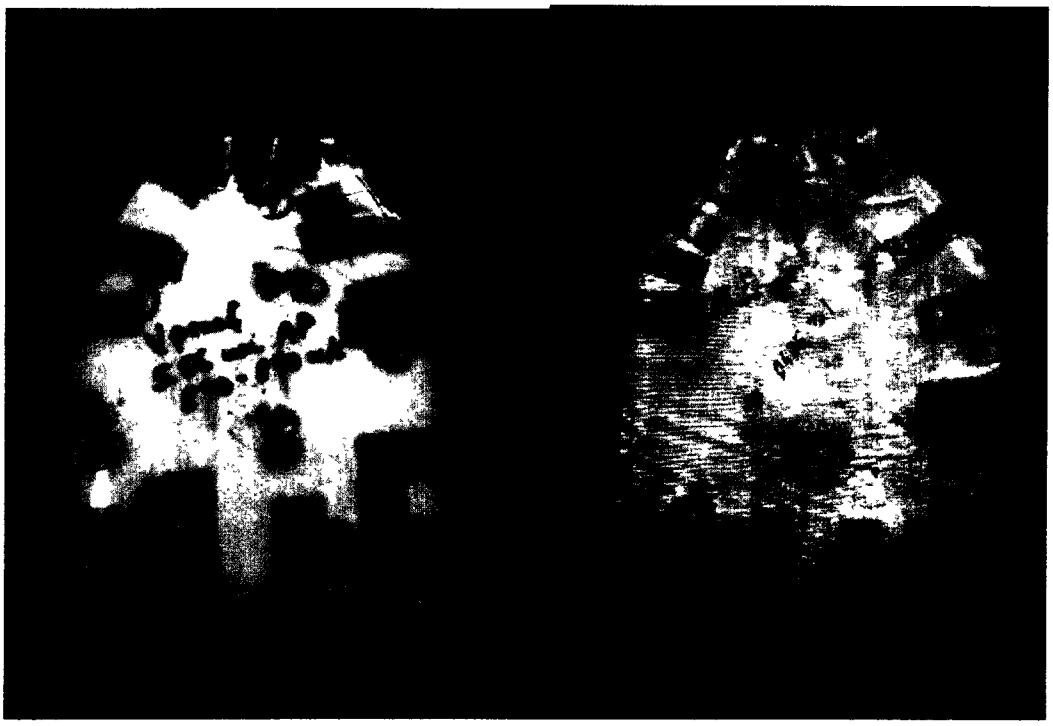

Figure 2. CERAMOR –STANDARD bullet resistant plate tested against 5.56 mm AP IP projectiles showing the multi-hit capabilities (strike face with 8 shots on the left; the back face on the right)..

Figure 3. CERAMOR –MAP bullet resistant plate tested against 7.62 mm Bofors and M2 projectiles at muzzle velocity (strike face –left side; back face-on the right).

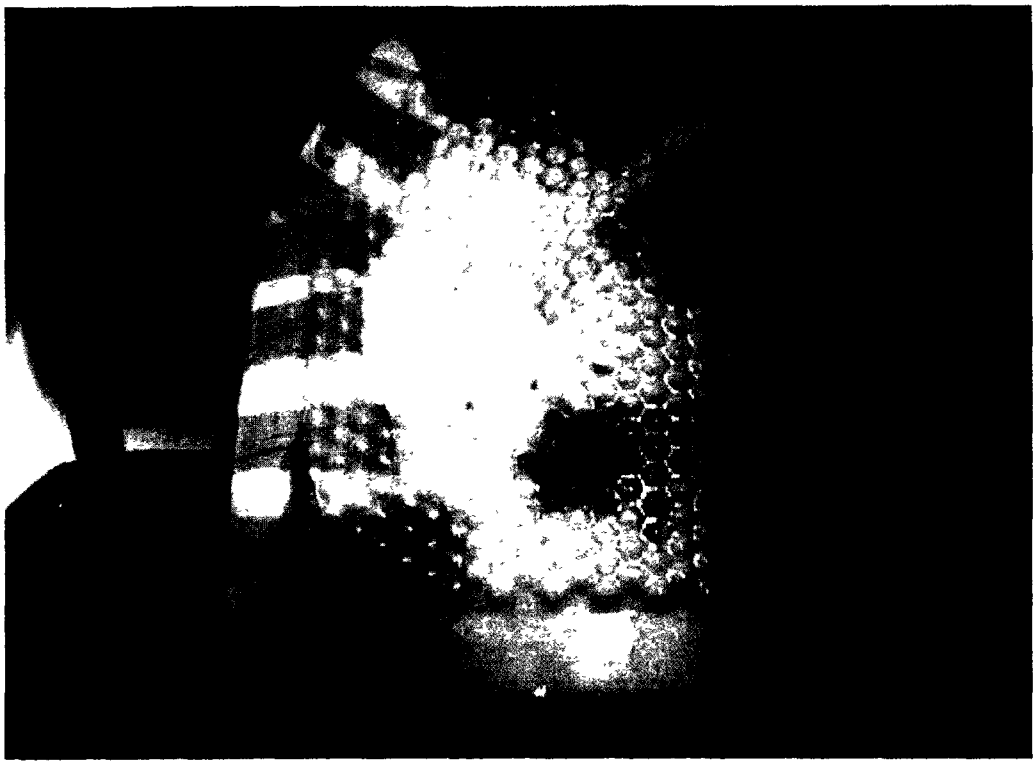

Figure 4a. The strike face of CERAMOR–MAP bullet resistant plate tested against 12.7 mm AP TC 44 projectile at 500 m/s as stand-alone.

Figure 4b. The back face of the CERAMOR –MAP bullet resistant plate tested against 12.7 mm AP TC 44 projectile at 500 m/s as stand-alone.

III. COMMERCIALIZATION

Part of our commitment, included in the final report were seven CERAMOR – MAP plates designed for protection against 12.7 mm @ 500 m/s that we have provided DRDC Valcartier for their own testing.

Through the duration of the project, the company has started its marketing efforts focussing initially on the Canadian market. The prospects for commercialisation are much better in USA and UK, where the CERAMOR bullet resistant plates have received a warm reception. The CERAMOR plates for NIJ level IV special are presently tested in both countries. The company has also secured financing for a full production subsidiary, CERAMOR Defense located in Watertown, New York.

CERAMOR Defense, as a NY company is well positioned to succeed in US for both the SAPI and SPEARS programs. A seminar at US Army Research Laboratory was well received and CERAMOR Defense is looking to expand into the armour for vehicle protection as well.

IV. CONCLUSIONS

In summary:

- *A new advanced armour system has been developed and used against different level of threats.*
- *CERAMOR bullet resistant plates were tested and qualified against various level of threats.*
- *The new products will be commercialized through CERAMOR Defense.*

REFERENCES

1) DIR Progress Report –DIR P001; March 21, 2001,
2) DIR Progress Report –DIR P002, May 24,2001
3) DIR Progress Report –DIR P003, June 22,2001
4) DIR Progress Report –DIR P004, August 28,2001
5) DIR Progress Report –DIR P005, November 2,2001
6) DIR Progress Report –DIR P006, January 2,2002
7) DIR Progress Report –DIR P007, February 25,2002
8) DIR Progress Report –DIR P008&9, June 28,2002
9) DIR Progress Report –DIR P010, August 9,2002
10) DIR Progress Report –DIR P011, September 16,2002
11) DIR Progress Report –DIR P012, October 25,2002

Distribution list

INTERNAL DISTRIBUTION

CR-2002-268

1- G. Bergeron (scientific authority)

1- H/WE

1- L/TE

2- Document Library

EXTERNAL DISTRIBUTION

CR-2002-268

1- DLR 5

1- DSTL 3

1- DBDO 5

1- Lcol Jacques Levesque

1- I. J. Craigie

1- DRDKIM

DOCUMENT CONTROL DATA

1. ORIGINATOR (name and address)
Petru G. Lucuta
ACERAM Technologies
140 Hickson Avenue, Kingston, Ontario
K7K 2N6

2. SECURITY CLASSIFICATION
(Including special warning terms if applicable)
Unclassified

3. TITLE (Its classification should be indicated by the appropriate abbreviation (S, C, R or U)
Development of Advanced Ceramic Armour Systems for Personal Protection (U)

4. AUTHORS (Last name, first name, middle initial. If military, show rank, e g Doe, Maj. John E)
Lucuta, Petru G.

5 DATE OF PUBLICATION (month and year)	6a. NO OF PAGES	6b .NO OF REFERENCES
December 2002	14	CR-2002-268

7 DESCRIPTIVE NOTES (the category of the document, e g. technical report, technical note or memorandum. Give the inclusive dates when a specific reporting period is covered.)
Defence-Industry Research (DIR) Final Technical Report

8. SPONSORING ACTIVITY (name and address)
Defence-Industry Research Program (DBDO)

9a. PROJECT OR GRANT NO. (Please specify whether project or grant)	9b. CONTRACT NO.
DIR W2207-00EV03	W2207-00EV03/001/SV
10a. ORIGINATOR'S DOCUMENT NUMBER	10b. OTHER DOCUMENT NOS
	N/A

11. DOCUMENT AVAILABILITY (any limitations on further dissemination of the document, other than those imposed by security classification)

- ☒ Unlimited distribution
- ☐ Restricted to contractors in approved countries (specify)
- ☐ Restricted to Canadian contractors (with need-to-know)
- ☐ Restricted to Government (with need-to-know)
- ☐ Restricted to Defense departments
- ☐ Others

12 DOCUMENT ANNOUNCEMENT (any limitation to the bibliographic announcement of this document This will normally correspond to the Document Availability (11). However, where further distribution (beyond the audience specified in 11) is possible, a wider announcement audience may be selected.)

13 ABSTRACT (a brief and factual summary of the document It may also appear elsewhere in the body of the document itself It is highly desirable that the abstract of classified documents be unclassified. Each paragraph of the abstract shall begin with an indication of the security classification of the information in the paragraph (unless the document itself is unclassified) represented as (S), (C), (R), or (U). It is not necessary to include here abstracts in both official languages unless the text is bilingual).

ACERAM Technologies in cooperation with DRDC Valcartier through an R&D project sponsored by the Defence Industrial Research (DIR) program have developed a new ultra-light advanced ceramic armour system – CERAMOR-MAP® (CERAmic arMOR Modular Advanced Protection) The new system has been designed specifically for improved personal protection, but could be modified for use as add on armour on vehicles as well. (U)

This report describes briefly the torso protection system consisting of a spall cover, CERAMOR chest plate, shock absorber and a commercial backing The advancements reside in materials selection including the CERAMOR ceramic composite, the system components and their design. The new armour system is based on a tougher ceramic composite material (CERAMOR®) that provides closer than ever multi-hit capability, and a novel design approach to the ceramic components and the entire system. The advances in design are based on a dual role played by the ceramic by deflecting before defeating the projectiles. (U)

Ballistic test results showing the ballistic limits for various levels of threats are also presented on NIJ Level III, Level IV Special and 12.7 mm APT C44 projectiles. CERAMOR-MAP® strike plates have proven to be resilient with excellent multi-hit at any level of threat The two project objectives were satisfied for both 12 7 mm APT C44 and 0 30 cal AP M2 projectiles with protection systems of 50 kg/m2 and 38 5 kg/m2, respectively In conclusion, the improved ballistic performance of the new Advanced Ceramic Armour System is outlined. (U)

14. KEYWORDS, DESCRIPTORS or IDENTIFIERS (technically meaningful terms or short phrases that characterize a document and could be helpful in cataloguing the document. They should be selected so that no security classification is required Identifiers, such as equipment model designation, trade name, military project code name, geographic location may also be included. If possible keywords should be selected from a published thesaurus, e.g Thesaurus of Engineering and Scientific Terms (TEST) and that thesaurus-identified If it is not possible to select indexing terms which are Unclassified, the classification of each should be indicated as with the title)

Ceramic material, Personal protection, Body armour,

#518505

CA021781