

METRIC

MIL-STD-376
28 June 1993

MILITARY STANDARD
BALLISTIC PERFORMANCE RANKING OF CERAMIC ARMOR PLATES
AGAINST HIGH DENSITY PENETRATORS



AMSC N/A

DISTRIBUTION STATEMENT A Approved for public release; distribution unlimited.

FSC 9350

FOREWORD

1. This military standard is approved for use by all Departments and Agencies of the Department of Defense.
2. Beneficial comments (recommendations, additions, deletions) and any pertinent data which may be of use in improving this document should be addressed to: Director, U.S. Army Research Laboratory, Materials Directorate, ATTN: AMSRL-MA-S, Watertown, MA 02172-0001 by using the Standardization Document Improvement Proposal (DD Form 1426) appearing at the end of this document or by letter.

CONTENTS

<u>PARAGRAPH</u>		<u>PAGE</u>
1.	SCOPE	1
1.1	Purpose	1
1.2	Application	1
1.3	Materials and test conditions	1
1.4	Limitations	1
2.	APPLICABLE DOCUMENTS.	2
2.1	Government documents.	2
2.1.1	Specifications, standards and handbooks	2
2.2	Order of precedence	2
3.	DEFINITIONS	4
4.	GENERAL REQUIREMENTS.	7
4.1	Target configuration and setup.	7
4.1.1	Ceramic tild and confinement frame.	7
4.1.2	Thickness of the ceramic plates	7
4.1.3	Backing plate	7
4.1.4	Target fixturing.	8
4.2	Projectile specifications	8
4.3	Test conditions	8
4.3.1	Launch system	8
4.3.1.1	Gun system and launch package	8
4.3.1.2	Propellant.	8
4.3.2	Launch parameters	8
4.4	Velocity measuring equipment.	8
4.4.1	Chronograph	9
4.4.2	Detectors	9
4.4.3	Flash radiography systems	9
5.	DETAILED REQUIREMENTS	10
5.1	Test conditions	10
5.2	Ballistic test procedure.	10
5.2.1	Firing practices.	10
5.2.4	Measurement of residual penetration	11
5.2.3	Baseline penetrator calibration	10
5.2.4	Quantity of test specimens.	11
5.2.5	Correction for striking velocity variation.	11
5.3	Ballistic test report	11
5.4	Ceramic performance evaluation.	12
5.4.1	Reference ceramics.	12
5.4.1.1	Aluminum oxide baseline	12
5.4.1.2	Boron carbide baseline.	12
5.4.1.3	Silicon carbide baseline.	12
5.4.1.4	Titanium diboride baseline.	12
5.4.2	Performance ranking of tested materials	13
5.4.3	Applications to variant test configurations	13
5.5	Acceptance and rejection.	13

CONTENTS

<u>PARAGRAPH</u>		<u>PAGE</u>
5.6	Test samples ownership.	13
5.7	Retests	13
5.8	Security classification of armor.	13
6.	NOTES	14
6.1	Intended use.	14
6.2	Issue of DODISS	14
6.3	Subject term (keyword) listing.	14
 <u>FIGURE</u>		
1	Standard target configuration	7
2	Standard target configuration	7
3	General schematic	8
4	Vernier measurements.	10
5	Penetration as a function of velocity for 91% W rod . .	18
6	90% aluminum oxide reference map.	19
7	Boron carbide reference map	19
8	Silicon carbide reference map	20
9	Titanium diboride reference map	20
 <u>APPENDICES</u>		
A	Armor specifications.	15
B	Armor references.	17
 <u>TABLE</u>		
I	Expected DOP values for Titanium Diboride for 30-180 kg/m ² AD.	22

WP# ID-3385A/DISC-0183A. FOR MTL USE ONLY

1. SCOPE

1.1 Purpose. The purpose of this standard is to provide a general methodology for the test equipment, procedures, targets, and terminology needed to develop ballistic performance evaluation and ranking of advanced armor materials against high-density eroding projectiles.

1.2 Application. This military standard is intended for use in performing ballistic tests on armor materials, selection of materials to employ in armor systems, and as a tool to promote research and development of new armor materials. The method and target assembly technique also provide a means to perform parametric analyses on the effects of material properties, and other factors such as tile size, confinement, and penetrator properties on ballistic performance.

1.3 Materials and test conditions. This ballistic test method is intended for application to armor ceramics and other low ductility materials, for projectiles of heavy alloy, long rod type, and the armor materials to be used with a stiff backing structure. Applications of the test methodology to armor metallic materials are feasible in some instances, but fall outside the scope of this document.

Examples of materials for which this test may be appropriately employed are:

- a. Single-phase ceramics (e.g. SiC, TiB₂)
- b. Multiple-phase ceramics (aluminas)
- c. Glasses
- d. Metal-infiltrated ceramic composites
- e. Low ductility metal-matrix composites

1.4 Limitations. This standard has the following limitations:

1.4.1 This standard does not take precedence over nor supersede existing armor specification ballistic test procedures.

1.4.2 Specific requirements for the ballistic testing of armor end items are not covered by this standard and must be specified in the appropriate detailed specification or contract.

1.4.3 Military activities or DoD contractors may use in-house ballistic test facilities and equipment not covered by this standard (e.g., MIL-STD-1161(GL)).

2. APPLICABLE DOCUMENTS

2.1 Government documents.

2.1.1 Specifications, standards, and handbooks. The following specifications, standards, and handbooks form a part of this document to the extent specified herein. Unless otherwise specified, the issues of these documents are those listed in the issue of the Department of Defense Index of Specifications and Standards (DODISS) and supplement thereto, cited in the solicitation.

SPECIFICATIONS

MILITARY

- MIL-A-12560 - Armor Plate, Steel, Wrought, Homogeneous (For Use in Combat Vehicles and for Ammunition Testing)
- MIL-P-46199(MR) - Plate: Aluminum Oxide Ceramic (For Use in Armor Composites)
- MIL-P-64151(MR) - Plate: Silicon Carbide Ceramic (For Use in Armor Composites)
- MIL-P-64152(MR) - Plate: Titanium Diboride Ceramic (For Use in Armor Composites)
- MIL-P-64153(MR) - Plate: Boron Carbide Ceramic (For Use in Armor Composites)

STANDARDS

MILITARY

MIL-STD-662 - V₅₀ Ballistic Test for Armor

(Copies of specifications, standards, handbooks, drawings, publications, and other Government documents required by contractors in connection with specific acquisition functions should be obtained from the contracting activity or as directed by the contracting activity.)

2.2 Order of precedence. In the event of a conflict between the text of this document and the references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

3. DEFINITIONS

Applique armor: Armor in a modular form that can be easily installed on or removed from a weapon system without adversely affecting its structural integrity or operation.

Areal density: A measure of the weight per unit area of armor material, commonly expressed in pounds per square foot (lb/ft²) or kilograms per square meter (kg/m²) of surface area.

Armor specifications: See Appendix A.

Armor: A shielding material provided for ballistic defeat of projectiles or fragments when inherent shielding is inadequate.

Armor ceramic: Any ceramic material which is employed as a component of an armor array for protection against projectiles. In this sense, includes glasses as well as polycrystalline materials.

Armor system: A combination of various armor materials with properties and geometry chosen to defeat one or more specific threat projectiles.

Ballistic acceptance test: A test performed to determine whether or not a lot of armor is ballistically acceptable for use in production armor items.

Ballistic screening test: A test performed to determine the performance level of an armor material relative to that of known standard materials. Employs a simplified configuration rather than a production armor design for the target.

Ballistic impact: Those impacts due to hits on the target by projectiles, fragments or other aerodynamically-effected threat mechanisms.

Ballistic limit, protection criteria (V50BL(P)): (See MIL-STD-662)

Ballistic limit: The minimum velocity at which a particular armor-piercing projectile has a specified probability of completely penetrating armor plate of given thickness and physical properties at a specified angle of obliquity. Because of the expense of firing tests and the impossibility of controlling striking velocity precisely, plus the existence of a zone of mixed results in which a projectile may completely penetrate or only partially penetrate under apparently identical conditions, statistical approaches are necessary, based upon limited firings. Certain approaches lead to approximation of the V₅₀ limit, that is, the velocity at which complete penetration and incomplete penetration are equally likely to occur. Some methods attempt to approximate the V₀ limit, that is, the maximum velocity at which no complete penetration will occur. Other methods attempt to approximate the V₁₀₀ limit, that is, the minimum velocity at which all projectiles will completely penetrate (See MIL-STD-662).

Ballistic resistance: A measure of the capability of a material or component to stop or reduce the impact velocity and mass of an impacting projectile or fragment.

Break screens: A screen with a conductive pattern printed on the surface which is broken (opened) by a projectile impacting the screen. Used to activate or deactivate a chronograph upon passage of a projectile.

Cell size: The lateral dimensions of an armor tile used in an armor array.

Ceramic percentage: The fraction of ceramic present in an armor system as determined from dividing the areal density of its ceramic components by the total areal density of the system.

Chronograph: An electronic instrument used to determine the time interval of projectile flight between two fixed stations.

Comminution: Fracture or fragmentation (of ceramic material) into fine particulates as a result of projectile impact.

Composite armor: An armor system consisting of two or more different armor materials bonded together to form a protective unit.

Confinement frame: A steel frame or other structural support surrounding a ceramic tile which serves to retain it in place after it is damaged by impact of a projectile.

DOP: Depth of residual penetration. In the context of this test standard, the length or depth of the penetration cavity of the projectile in the steel backing plate after passing through the ceramic.

Fair test: A test shot shall be considered fair when a test projectile having total yaw under 3 degrees strikes the target within a radius equal to two penetrator diameters of the exact tile center.

Integral armor: Armor material used as part of a structure to perform a load-carrying or other operational function, in addition to ballistic protection. (also known as structural armor)

Long rod penetrator: Any projectile having a length to diameter (aspect) ratio greater than five.

Lumiline screens: Photoelectric device used to activate or deactivate a chronograph upon passage of a projectile.

Muzzle velocity: The velocity of the projectile immediately upon exiting the muzzle of the weapon barrel. This velocity is a function of projectile weight, projectile-bore frictional characteristics, propellant charge, barrel length, ambient temperature, etc.

Obliquity: Angle between a projectile's line-of-flight and the surface normal to the target face.

Obturator: A component of the sabot package which serves as a bore seal.

Overmatching: As used herein, a condition in which the penetration capability of the projectile is much greater than the stopping capability of the armor or armor material. Also used in association with steel armor, where it indicates that the diameter of the impacting projectile is larger than the thickness of the armor plate.

MIL-STD-376

Penetration, reference (Po): The depth to which the standard test projectile penetrates when fired at the standard striking velocity into a semi-infinite RHA steel block.

Penetration, residual (Pr): In general, the length or depth of the penetration cavity of a projectile into a witness pack or plate. As applied herein, the penetration in the steel backup block behind the ceramic target assembly. (See also DOP)

Performance map, ballistic: A plot of residual penetration as a function of areal density of armor ceramic.

Propellant: A low explosive material whose combustion provides the hot gases that propel the projectile through the gun bore.

Pusher: A metallic disk used to transmit launch loads to the base of a projectile when a traction-launch system is not employed.

Rolled Homogeneous Armor (RHA): Armor steel produced as per the requirements of MIL-A-12560.

Sabot: Lightweight carrier in which a subcaliber projectile is centered to permit firing the projectile in the larger caliber weapon. The sabot diameter fills the bore of the weapon from which the projectile is fired. Sabots may either detach from the projectile upon exit from the muzzle (discarding), or remain attached in flight (integral).

Semi-infinite: As related to penetration of a thick target, implies that the rear surface of the plate receives only elastic loading, with no permanent deformation being discernible.

Small arms ammunition: Ammunition for small arms, i.e., all ammunition up to and including 20 millimeters (0.787 inches).

Small arms: All arms, including automatic weapons, up to and including 20 millimeters (0.787 inches).

Spaced armor: Armor systems which incorporate distinct spaces between armor elements.

Spalling: The detachment or delamination of a layer of material in the area surrounding the location of impact, which may occur on both the front and rear surfaces of the armor.

Striking velocity: The velocity of a projectile at the instant of impact on the target (also known as impact velocity).

Target base line: The distance from a point midway between two chronographic triggering devices and the test panel.

Terminal ballistics: A branch of ballistics which is concerned with the principles underlying the effects of weapons on targets including penetration, fragmentation, detonation, shaped charge, blast, combustion and incendiary effects.

Test sample: A section of an armor plate or fabricated armor component which is to be ballistically tested for evaluation of ballistic properties.

Tungsten heavy alloy: A high density composite material consisting of a large (usually >90%) weight fraction of tungsten particles bound in a matrix material, which is usually a Ni-Fe alloy. Commonly used to make long rod penetrators.

Undermatch: As used herein, a condition in which the penetration capability of the projectile is much lower than the stopping capability of the armor or armor material. Also used in association with steel armor, where it indicates that the diameter of the impacting projectile is less than the thickness of the armor plate.

V₅₀ ballistic limit: In general, the velocity at which the probability of penetration of an armor plate or package is 50 percent.

Witness plate: A thin sheet located behind and parallel to the ballistic test sample which is used to detect penetrating projectiles or spall.

Yaw: The maximum angular deviation of the longitudinal axis of the projectile from the line of flight measured at a point as close to the impact point on the target as is reasonably practical.

MIL-STD-376

4. GENERAL REQUIREMENTS

4.1 Target configuration and setup.

4.1.1 Ceramic tile and confinement frame. The standard target configuration to be employed in these tests is shown in figures 1 and 2. The target consists of a 15 cm by 15 cm square ceramic tile of a chosen thickness (t), which is laterally confined in a steel frame with a 2.5 cm web and a depth equal to or greater than the tile thickness. No cover plate is employed. A polymeric adhesive is used to retain the tile in the frame, in addition to being spread in a thin layer (approximately 0.5 mm) behind the tile to accommodate any slight surface irregularities, thus preventing nonuniform contact between the ceramic and the backing plate. The use of a 5 kg load uniformly distributed on the ceramic plate during the adhesive curing cycle is recommended. Two fabrication options are permissible:

a) a 0.5 mm aluminum sheet may be used behind the tile to contain the epoxy within the frame.

b) the confinement frame and ceramic may be attached directly to the surface of the backing plate (4.1.2) by the adhesive.

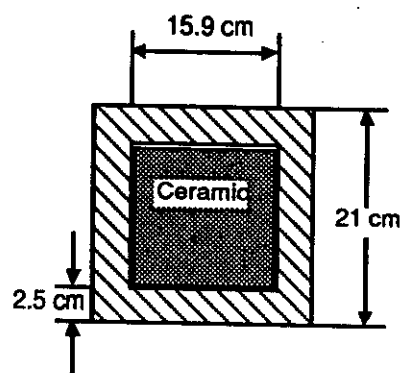


Figure 1

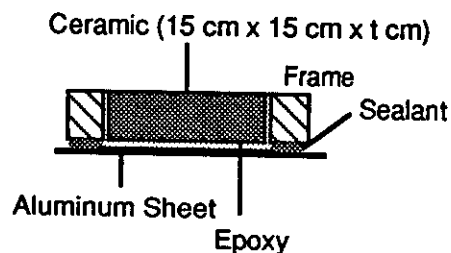


Figure 2

FIGURE 1. & FIGURE 2. Standard target configuration.

4.1.2 Thickness of the ceramic plates. Thickness of the ceramic plates should vary no more than $\pm 3\%$ for any given series of targets.

4.1.3 Backing plate. The backup plate employed shall be RHA steel (MIL-A-12560, Class 1 or Class 3) of a thickness sufficient to be effectively semi-infinite or with respect to the residual penetration of the tested projectile/material combination. The hardness level of the steel plate shall be in the range of 26 ± 1.5 on the Rockwell "C" scale. Commonly employed plate thicknesses are 10 cm and 12.5 cm (Specification requirements for this steel mandate approximately this hardness range for these thicknesses.) The plates shall have a surface finish of 13.2 m. If RHA steel is not readily available, 4340 steel at the specified hardness level may be substituted.

4.1.4 Target fixturing. If 4.1.1a is followed, ceramic target assemblies will be mechanically clamped against the steel backup block for testing, and removed after firing. Clamping shall be performed so as to produce uniform contact between the ceramic target assembly and the steel block. Visual inspection should show no gap between the target assembly and the block. In either case, the target system shall be supported on a test table or other fixture such that it is properly restrained and that the target face is normal to the projectile line-of-flight. Figure 3 presents a general schematic.

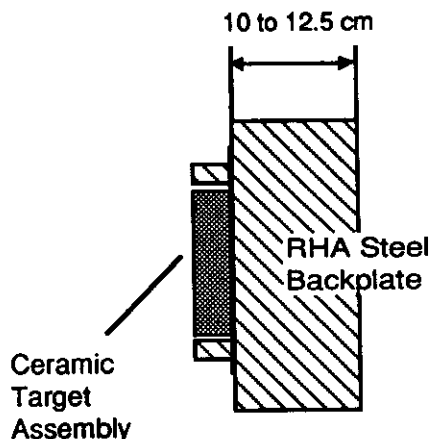


FIGURE 3. General schematic.

4.2 Projectile specifications. The standard projectile employed shall be a long rod penetrator with a mass of 65 ± 0.25 g and an aspect ratio of 10:1. It should have an hemispherical nose and preferably shall not be threaded or grooved for traction launch. The alloy used should be either a 91% or 93% tungsten heavy alloy composition, with a minimum ultimate tensile strength (UTS) of 1000 MPa and elongation of 5%. Exact projectile dimensions will vary with the alloy density. By way of example, a penetrator fabricated from a 91% tungsten heavy alloy, with a density of 17.45 g/cc, will have a diameter of 7.87 mm.

4.3 Test conditions

4.3.1 Launch system. The penetrator may be launched by any normal ballistic test practice which will consistently achieve the desired launch velocity and yaw control parameters.

4.3.1.1 Gun system and launch package. The suggested configuration is to employ a pusher-type sabot package, fired from a smooth-bore test barrel of at least 20mm bore diameter.

4.3.1.1 Propellant. Any propellant which is either standard or suitable for the weapon shall be used. A projectile velocity-propellant charge curve for the weapon shall be determined before any testing is performed. This curve is required to provide a basis for selecting a powder charge to achieve the desired velocity. It is recommended that the propellant storage and weighing area be maintained at $23 \pm 2^\circ\text{C}$ and $50 \pm 5\%$ relative humidity.

4.3.2 Launch parameters. The nominal test velocity employed for ceramic testing is 1500 m/s. All baseline performance data cited in Section 5 of this specification were obtained at this test velocity. In some instances,

MIL-STD-376

variations from this reference velocity may be desired, but this introduces the need to perform additional baseline material performance tests at the selected velocity. To ensure a fair test, total projectile yaw must be under 3 degrees.

4.4 Velocity measuring equipment.

4.4.1 Chronograph. An electronic counter type chronograph measuring to at least the nearest microsecond ($10^{-6}s$) shall be used.

4.4.2 Detectors. Either high-velocity lumiline screens, or electrical contact screens which either open or close an electrical circuit by passage of the projectile through the detector shall be used. Contact screens may consist of metallic foils separated by a thin insulating layer, or may consist of a circuit printed on paper with the circuit spacing such that the projectile passing through the screen will "break" the circuit. This system may be employed in order to provide a starting time for operation of the flash x-ray system, and will also provide a check velocity in the event of timer failures in the x-ray system.

4.4.3 Flash Radiography System. Measurement of the projectile yaw and velocity shall be accomplished by a flash radiography system. Exact setup and nature of the system shall be in accordance with established range procedures and the operational requirements of the specific equipment being employed. Total yaw and velocity of the projectile will be measured from two sets of orthogonal radiographs in accordance with appropriate practices for the system setup being employed. Striking velocity shall be recorded to within 1 m/s, and yaw shall be determined in increments of no greater than 0.25 degrees.

5. DETAILED REQUIREMENTS

5.1 Test conditions. Insofar as is possible, all ballistic tests shall be performed in a standard atmosphere of $23 \pm 2^\circ\text{C}$ and $50 \pm 5\%$ relative humidity. These conditions are recommended in order to provide for optimal control of projectile velocities.

5.2 Ballistic test procedure. The procedure listed below is a general description of the method for obtaining residual penetration data on a ceramic or other type of target material. One should note that the actual method to be used may vary depending on target composition, specification or contract requirement.

5.2.1 Firing practices. All ballistic tests shall be conducted in accordance with commonly accepted procedures for the particular gun setup being employed, in a manner which complies with the requirements of Section 4. All appropriate general safety procedures applicable to the performance of ballistic tests shall be followed, including any accepted local regulations as implemented at particular installations.

5.2.2 Measurement of residual penetration. All residual penetration measurements will be made directly from sections of the RHA steel block. A saw or other appropriate cutting tool (e.g. a wire EDM unit) shall be used to section all penetration cavities. Measurements should be made with vernier calipers on both sides of the cavity sections as indicated in figure 4, choosing the lower of the resultant values for "a". Measurement of the "a" value in this way avoids error which will be caused by deformation of the steel block around the entrance cavity. When the cavity is non-uniform, the portion which shows the deepest penetration (i.e., the lowest "a" value) shall be chosen.

$$\text{DOP} = T_b - a$$

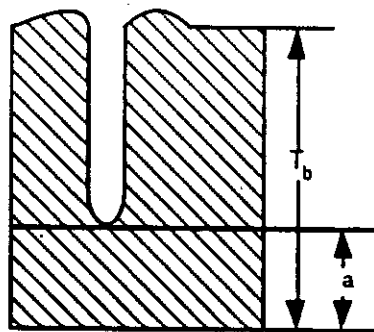


FIGURE 4. Vernier measurements.

5.2.3 Baseline penetrator calibration. In order to provide a suitable set of baseline data for residual penetration into the RHA steel backup, a minimum of 8 tests evenly spaced over a velocity range from 1000 m/s to 1700 m/s shall be performed. This procedure need only be performed once to cover any individual lot of penetrators obtained at one time from a single manufacturer. If the penetrator is a 91%W to 93%W long rod with the specified 10:1 aspect ratio and 65 g mass, the following equation may be employed to determine reference penetration as a function of velocity over a range from 800 to 1750 m/s. A graphical representation of this plot is shown in figure 5.

$$\text{DOP (mm)} = -55.734 + (0.08342 \times V_s)$$

(Equation 1)

with V_s being the striking velocity in units of m/s.

5.2.4 Quantity of test specimens. Test targets shall be prepared in keeping with the parameters given in 4.1. For each ceramic material which is to be tested, a minimum of three (3) fair impacts shall be obtained. A fair impact is a shot which has a total yaw of under 3 degrees, and a striking velocity within ± 25 m/s of the chosen nominal test velocity (see 4.3.2). In addition, the shot must impact the target within a distance of two penetrator diameters from the geometrical center of the ceramic plate, and there must not be any visible deformation or bulging of the rear surface of the RHA steel block. Sufficient targets shall be tested to obtain the required three fair impacts.

5.2.5 Corrections for striking velocity variations. In order to normalize all penetration values to the nominal striking velocity, the measured DOP values should be corrected by application of Equation 2.

$$\text{DOP}_{\text{corrected}} (\text{mm}) = \text{DOP}_{\text{measured}} (\text{mm}) + (0.08342 \times (1500 - V_s))$$

(Equation 2.)

where $\text{DOP}_{\text{corrected}}$ is the corrected residual penetration, $\text{DOP}_{\text{measured}}$ is the measured residual penetration, and V_s is the striking velocity in m/s.

5.3 Ballistic test report. It is recommended that ballistic test reports have the following information:

For each test series:

- a. Contractor identification.
- b. Contract number.
- c. Material producer test facility.
- d. Date test conducted.
- e. Personnel conducting test and any witnesses.
- f. Projectile used.
- g. Armor material description.

For each test target:

- a. Identification number for each material sample (including lot numbers).
- b. Projectile mass, g.
- c. Striking velocity (as determined from flight radiographs).
- d. Total projectile yaw (as determined from flight radiographs).
- e. Measured block thickness (T_b)
- f. Cavity-rear surface thickness (a).
- g. Calculated DOP.
- h. Other remarks pertinent to the conduct of the test, or behavior of the material.

Additional data may be required by a contracting activity. When testing is done at a place other than a Government facility, results should be reported on forms either furnished or approved by the Government. One copy of each complete report shall be forwarded to the agency designated by the Government.

5.4 Ceramic performance evaluation

5.4.1 Reference ceramics. Reference maps for the performance of four armor ceramics are available for comparison with test materials. These reference materials are:

- a. 90% Aluminum Oxide (applicable to materials covered under Classes 1-3 of MIL-P-46199(MR))
- b. Boron Carbide (applicable to materials covered under MIL-P-64153(MR))
- c. Silicon Carbide (applicable to materials covered under MIL-P-64151(MR))
- d. Titanium Diboride (applicable to materials covered under MIL-P-64152(MR))

Test materials should be related to reference materials on the basis of bulk density. For example the appropriate reference material to use for comparisons of titanium carbide (TiC) at 4.9 g/cc would be item d, titanium diboride.

5.4.1.1 Aluminum oxide baseline. The baseline performance map is shown in figure 6. For this material, the residual penetration may be obtained from the following equation:

$$\text{DOP (mm)} = 63.98 - (0.1907 \times \text{AD}) \quad (\text{Equation 3})$$

with AD being the areal density in units of Kg/m^2 . This is valid over the range of areal densities from 50 to 270 kg/m^2 .

5.4.1.2 Boron carbide baseline. The baseline performance map is shown in figure 7. For this material, the residual penetration may be obtained from the following equation:

$$\text{DOP (mm)} = 54.08 - (0.2357 \times \text{AD}) \quad (\text{Equation 4})$$

with AD being the areal density in units of kg/m^2 . This is valid over the range of areal densities from 60 to 130 kg/m^2 .

5.4.1.3 Silicon carbide baseline. The baseline performance map is shown in figure 8. For this material, the residual penetration must be obtained from the following equation:

$$\text{DOP (mm)} = 3508 * \text{AD}^{\text{expo}(-1.126)} \quad (\text{Equation 5})$$

with AD being the areal density in units of kg/m^2 . Valid comparisons may be made over the range of areal densities from 60 to 220 kg/m^2 .

5.4.1.4 Titanium diboride baseline. The baseline performance map is shown in figure 9. No equation of fit is available for this material. The residual penetration should be obtained either directly from the curve, or by reference to the data given in table I, which contains expected DOP values for a range of areal densities between 30 and 180 kg/m^2 (i.e., over the complete extent of the curve. Valid comparisons may be made over the range of areal densities from 70 to 150 kg/m^2 .

5.4.2 Performance ranking of tested materials. The performance of the tested ceramic or other material may be related to the reference ceramic by determining the residual penetration (DOP) for the appropriate reference material (as indicated in 5.4.1 above), and comparing this to the average value of DOP obtained from the requisite three fair impacts on the tested ceramic. Comparison of DOP values are made at equal areal density of reference and trial materials. The resultant difference provides the basis for comparison. A qualitative result can be determined based upon the position of the tested material relative to the baseline material. A tested material which exhibits an increased residual penetration has a lower performance, and one which exhibits a reduced residual penetration from the reference material has an improved performance. Quantitative comparisons may be made in terms of percentage differences between DOP values obtained for the tested and reference materials.

5.4.3 Applications to variant test configurations. If it is desired to perform residual penetration screening tests employing a penetrator or a test condition not explicitly set out or incorporated in this standard, the methods and approach employed should parallel the ones set forth herein as much as is possible. It should be recognized that significant variation from the test conditions described by this standard may require extensive work to provide suitable baseline data sets for both penetrator calibration and reference material performance maps. This fact should be kept in mind when determining whether a variant test configuration is desirable.

5.5 Acceptance and rejection. If this test method is employed as a purchasing guidance tool, the selected material samples must meet the minimum ballistic requirements specified in the order for the represented lot to be acceptable. Failure of any averaged series of test samples to meet the minimum specified ballistic performance level shall constitute rejection of the entire lot which they represent. Unless otherwise specified, the ballistic tests shall be conducted and the test results considered prior to accepting shipment of the lot of material represented by the test samples.

5.6 Test samples ownership. Ballistic test samples that comply with ballistic requirements are considered as part of the lot of material they represent, and ownership of them passes to the Government upon acceptance. The Government inspector shall dispose of these test samples unless instructed otherwise by the procuring activity. Test samples that fail to comply with the ballistic requirements are considered as part of the lot they represent and remain the property of the supplier just as does the rejected lot they represent.

5.7 Retests. Reference shall be made to the appropriate specification or applicable test directive for guidance on the number of retest samples required, if such are allowed. If the retest samples do not pass the ballistic test, the lot from which they came, or the process by which they were made is permanently rejected. Otherwise, if all retest samples pass, the lot or process is accepted.

5.8 Security classification of armor. Terminal ballistics performance data on armor materials shall be classified in accordance with USAMTL MSR No. 01813009, "Security Classification Guide for Armor Materials".

6. NOTES

(This section contains information of a general or explanatory nature that may be helpful, but is not mandatory.)

6.1 Intended use. This standard is intended for the ballistic evaluation of ceramic plates used in armor systems (see 1.2 and 1.3).

6.2 Issue of DODISS. When this standard is used in acquisition, the applicable issue of the DODISS must be cited in the solicitation (see 2.1 and 2.2).

6.3 Subject term (keyword) listing.

long rod penetrator	aluminum oxide plate
flash radiography	boron carbide plate
depth of penetration	silicon carbide plate
	titanium diboride plate

Custodians:

Army - MR
Navy - SH
Air Force - 18

Preparing activity:

Army - MR

Project 9350-1009

Review activities:

Army - TE
Navy - AS

MIL-STD-376

APPENDIX A

ARMOR SPECIFICATIONS

This appendix is a compilation of military specifications for armor which is intended for reference purposes.

Aluminum Armor

MIL-A-45225(MR)	Aluminum Alloy Armor, Forged	30 Nov 1976
MIL-A-46027(MR)	Armor Plate, Aluminum Alloy, Weldable 5083 and 5456	6 Jan 1984
MIL-A-46063	Armor Plate, Aluminum Alloy, 7039	10 Mar 1977
MIL-A-46083(MR)	Aluminum Alloy Armor, Extruded, Weldable	16 May 1977
MIL-A-46118(MR)	Aluminum Alloy Armor, 2219, Rolled Plate and Die Forged Shapes	19 Dec 1983

Body Armor

MIL-C-12369(GL)	Cloth, Ballistic, Nylon	28 Jun 1974
MIL-A-17367(MC)	Armor, Body, Fragmentation Protective: Upper Torso (With Collar, M-1955)	3 Oct 1977
MIL-I-17368(MC)	Insert, Body Armor	23 Nov 1977
MIL-I-43903	Insert, Small Arms Protective Body Armor,	

Aircraftman

	9 Oct 1974	
MIL-C-44050	Cloth, Ballistic, Aramid	15 Sep 1981
MIL-B-44053	Body Armor, Fragmentation Protective Vest, Ground Troops	29 Sep 1981
MIL-H-44099	Helmet, Ground Troops', Parachutists'	10 Mar 1983

Ceramic Materials

MIL-P-46199(MR)	Plate: Aluminum Oxide Ceramic (For Use in Armor Composites)	Jul 1989
MIL-P-64151(MR)	Plate: Silicon Carbide Ceramic (For Use in Armor Composites)	Jul 1989
MIL-P-64152(MR)	Plate: Titanium Diboride Ceramic (For Use in Armor Composites)	Jul 1989
MIL-P-64153(MR)	Plate: Boron Carbide Ceramic (For Use in Armor Composites)	Jul 1989

Composite Armor

MIL-A-46103	Armor: Lightweight, Ceramic-Faced Composite, Procedure Requirements	23 Jul 1981
MIL-A-46108	Armor: Transparent, Glass; Glass/Plastic; Plastic Laminates; (General Specification)	8 Aug 1983
MIL-A-46165(MR)	Armor: Woven Glass Roving Fabrics	6 Dec 1973
MIL-A-46166(MR)	Armor: Glass Reinforced Plastic Laminates	Dec 1973

APPENDIX A

MIL-A-62473(AT)	Armor: Aluminum-Aramid, Laminate Composite	24 Jan 1984
MIL-L-62474(AT)	Laminate: Aramid-Fabric Reinforced, Plastic	25 Jun 1984
Steel Armor		
MIL-A-11356(MR)	Armor, Steel, Cast, Homogeneous, Combat-Vehicle Type (1/4 to 8 Inches, Inclusive)	5 Feb 1974
MIL-A-12560(MR)	Armor Plate, Steel, Wrought, Homogeneous (For Use in Combat-Vehicles and for Ammunition Testing)	15 Aug 1984
MIL-A-13259(MR)	Armor, Steel: Sheet, Strip, and Fabricated Forms; Rolled, Non-magnetic; For Helmets and Personnel Armor Requirements	6 May 1966
MIL-A-46099	Armor Plate, Steel, Roll-Bonded, Dual Hardness	9 Nov 1976
MIL-A-46100	Armor Plate, Steel, Wrought, High-Hardness	13 Jun 1983
MIL-A-46186(MR)	Armor Plate, Steel, Wrought, High Strength, High-Quality	11 Jun 1984
MIL-S-46188(MR)	Steel Plate, Wrought Homogeneous Electrosag Remelt (ESR) (4340 Alloy)	16 May 1985
Titanium Armor		
MIL-A-46077	Armor Plate, Titanium Alloy, Weldable	28 Apr 1978

MIL-STD-376

APPENDIX B

ARMOR REFERENCES

Air Force Wright Aeronautical Laboratories (AFWAL)

AFWAL-TR-82-4163	Armor for Air Force Tactical Shelters
(Volume I)	(Nov 1982)

Army Materiel Command (AMC)

AMCP 706-107	Engineering Design Handbook: Elements of Armament Engineering, Part Two - Ballistics (Chapter 10) (September 1963)
--------------	--

AMCP 706-170	Engineering Design Handbook: Armor and its Applications (November 1973) (SECRET)
--------------	---

National Institute of Justice (NIJ)

NIJ Standard 0101.02 Ballistic Resistance of Police Body Armor

MIL-STD-376

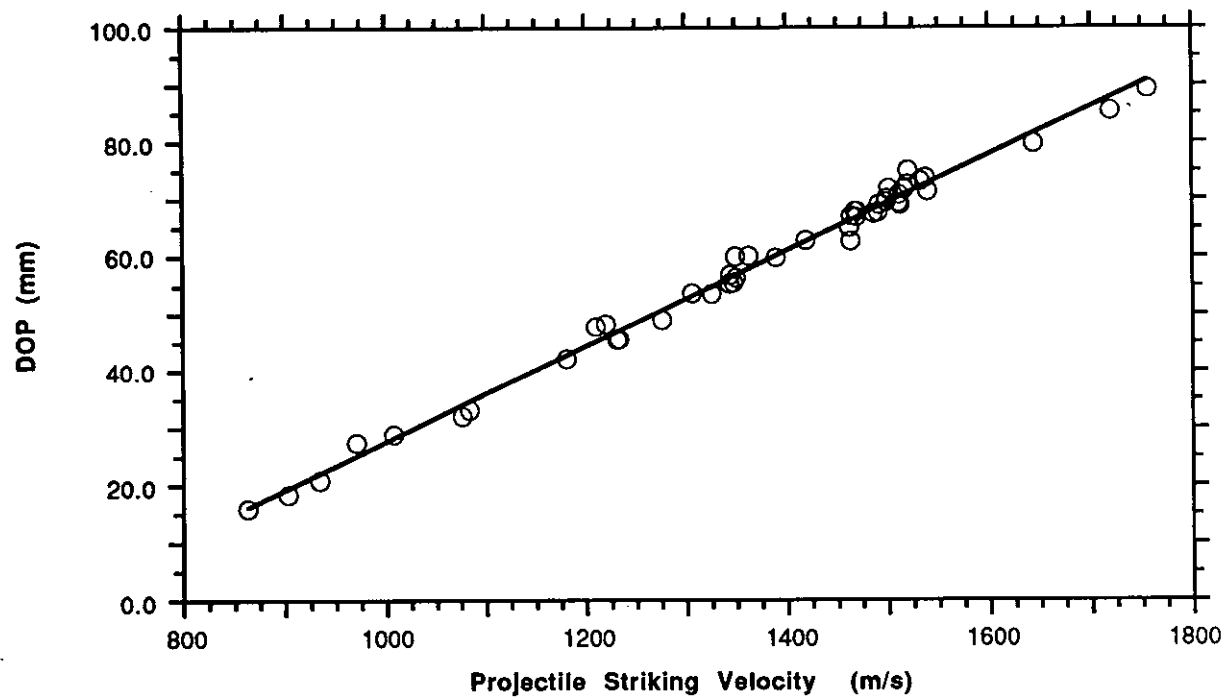


Figure 5. Penetration depth in RHA steel as a function of projectile velocity for 91%W rod

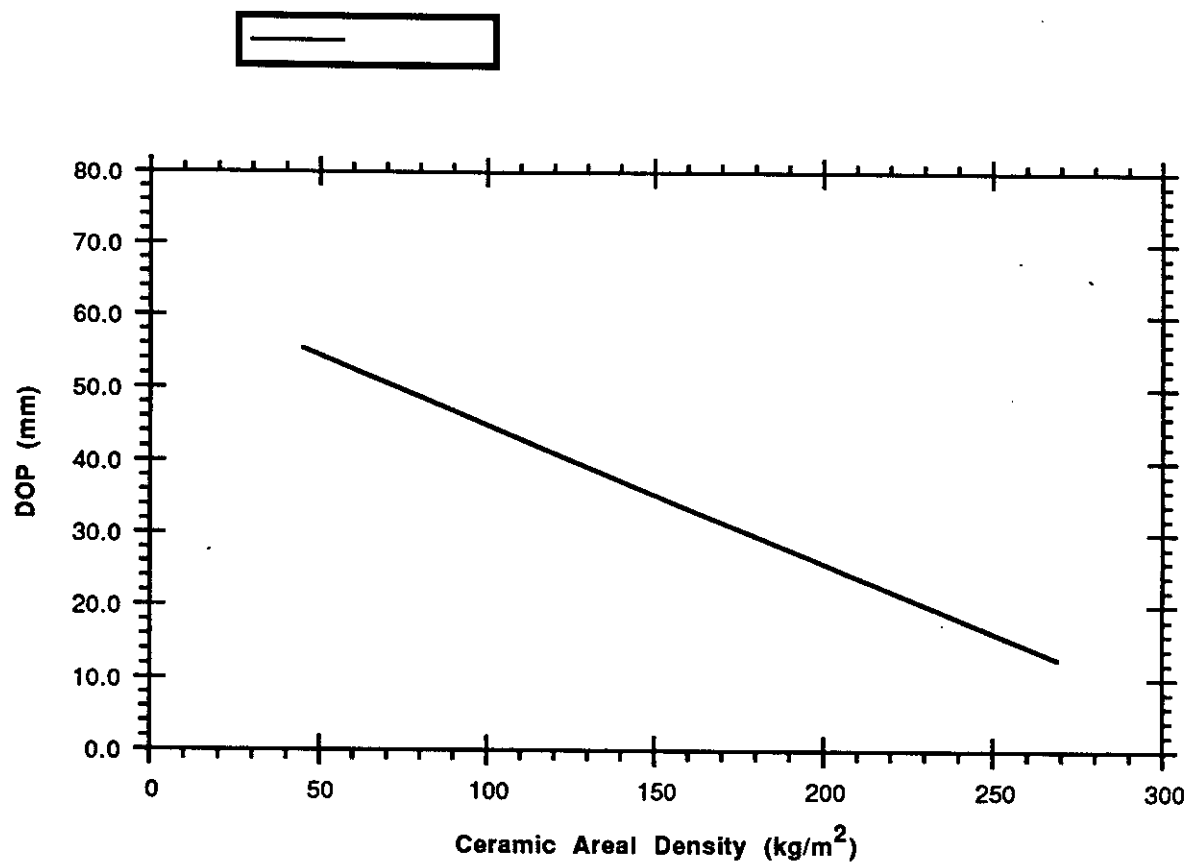


Figure 6. 90% aluminum oxide reference map

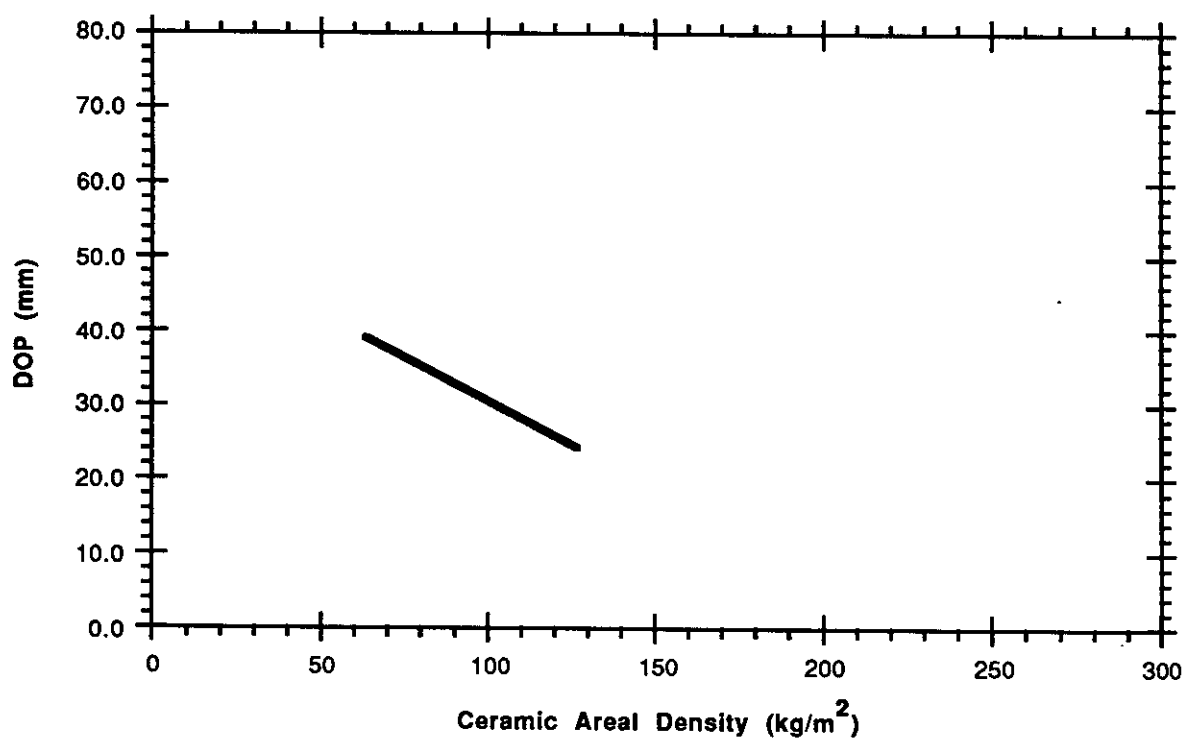


Figure 7. Boron carbide reference map

MIL-STD-376

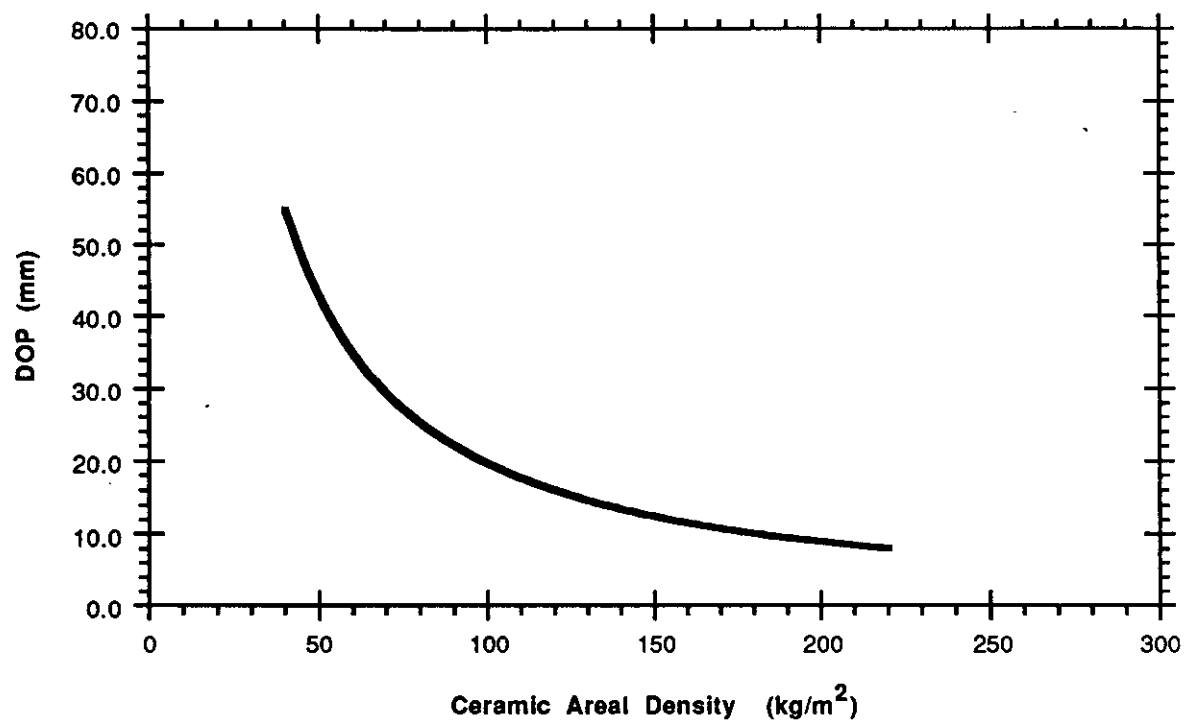


Figure 8. Silicon carbide reference map

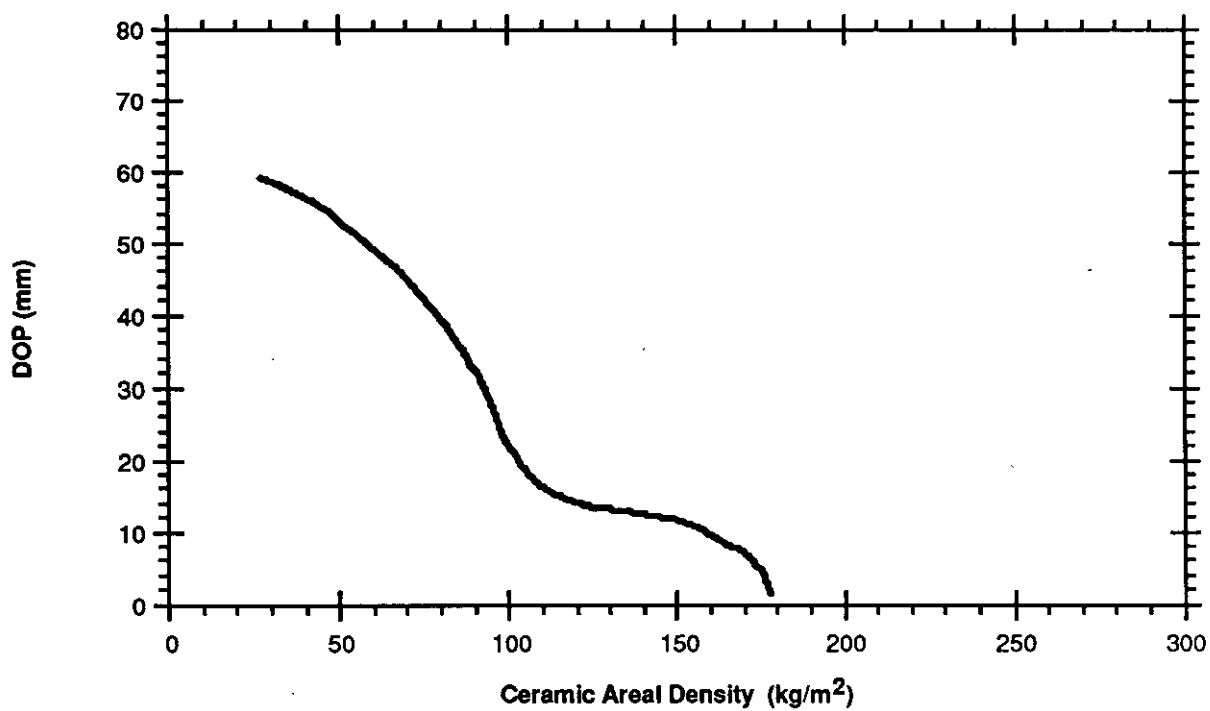


Figure 9. Titanium diboride reference map

MIL-STD-376

TABLE I. Expected DOP values for titanium diboride
for 30-180 kg/m² areal densities.

AD (kg/m ²)	DOP (mm)	AD (kg/m ²)	DOP (mm)
29.5	58.5	112.5	15.5
32.5	58.0	115.5	14.5
35.5	57.4	119.0	14.0
38.5	56.5	121.5	13.5
41.5	55.5	124.5	13.0
44.5	55.0	127.5	13.0
47.5	54.0	130.5	13.0
50.5	53.0	133.5	12.5
53.5	51.5	136.5	12.5
56.5	50.5	139.0	12.0
59.0	49.5	142.5	11.5
62.5	48.5	145.5	11.5
65.0	47.0	148.0	11.5
68.0	46.0	151.0	11.0
71.0	44.5	154.0	10.5
74.0	43.0	157.0	10.5
77.0	41.5	160.0	9.0
80.0	40.0	163.0	8.5
83.0	37.5	166.0	7.5
85.0	35.5	169.0	7.0
89.0	33.5	172.0	6.0
92.0	31.5	175.0	5.0
95.0	28.5	178.0	2.0
98.0	25.0	181.0	0.0
101.0	21.5		
104.0	20.0		
107.0	17.5		
110.0	16.5		

STANDARDIZATION DOCUMENT IMPROVEMENT PROPOSAL

INSTRUCTIONS

1. The preparing activity must complete blocks 1, 2, 3, and 8. In block 1, both the document number and revision letter should be given.
2. The submitter of this form must complete blocks 4, 5, 6, and 7.
3. The preparing activity must provide a reply within 30 days from receipt of the form.

NOTE: This form may not be used to request copies of documents, nor to request waivers, or clarification of requirements on current contracts. Comments submitted on this form do not constitute or imply authorization to waive any portion of the referenced document(s) or to amend contractual requirements.

I RECOMMEND A CHANGE:		1. DOCUMENT NUMBER MIL-STD-376	2. DOCUMENT DATE (YYMMDD)
3. DOCUMENT TITLE BALLISTIC PERFORMANCE RANKING OF CERAMIC ARMOR PLATES AGAINST HIGH DENSITY PENETRATORS			
4. NATURE OF CHANGE (Identify paragraph number and include proposed rewrite, if possible. Attach extra sheets as needed.)			
5. REASON FOR RECOMMENDATION			
6. SUBMITTER			
a. NAME (Last, First, Middle Initial)		b. ORGANIZATION	
c. ADDRESS (Include Zip Code)		d. TELEPHONE (Include Area Code) (1) Commercial (2) AUTOVON (If applicable)	7. DATE SUBMITTED (YYMMDD)
8. PREPARING ACTIVITY			
Commander/Director US Army Materials Technology Laboratory ATTN: SLCMT-MEE Watertown, MA 02172-0001		b. TELEPHONE (Include Area Code) (1) Commercial 617-923-5286 (2) AUTOVON DSN955-5286	
IF YOU DO NOT RECEIVE A REPLY WITHIN 45 DAYS, CONTACT: Defense Quality and Standardization Office 5203 Leesburg Pike, Suite 1403, Falls Church, VA 22041-3466 Telephone (703) 756-2340 AUTOVON 289-2340			