PHOTOGRAPH THIS SHEET

AD A950525

DTIC ACCESSION NUMBER

LEVEL

Watertown Arsenal Lab, MA

INVENTORY

Rept. No. WAL-TR-241/1

DOCUMENT IDENTIFICATION

Mar. 59

DISTRIBUTION STATEMENT A

Approved for public release;
Distribution Unlimited

DISTRIBUTION STATEMENT

| ACCESSION FOR | | |
|---|---|---|
| NTIS | GRA&I | ☒ |
| DTIC | TAB | ☐ |
| UNANNOUNCED | | ☐ |
| JUSTIFICATION | | |
| (Mar. 1959) | | |
| BY | | |
| DISTRIBUTION / Per Ltr. on File | | |
| AVAILABILITY CODES | | |
| DIST | AVAIL AND/OR SPECIAL | |
| A | | |

DISTRIBUTION STAMP

Released

UNANNOUNCED

DTIC
ELECTE
JUN 17 1981
S D
D

DATE ACCESSIONED

81 6 16 010

DATE RECEIVED IN DTIC

PHOTOGRAPH THIS SHEET AND RETURN TO DTIC-DDA-2

DTIC FORM OCT 79 70A

DOCUMENT PROCESSING SHEET

# WATERTOWN ARSENAL LABORATORIES

## ARMOR-PIERCING SHOT PROCESSED FROM MOLYBDENUM BEARING TUNGSTEN CARBIDE

TECHNICAL REPORT NO. WAL TR 241/1

BY

C. A. RIDDLE

MARCH 1959

O.O. PROJECT: TW-426, SUPPORTING RESEARCH ON ARMOR-PIERCING PROJECTILES
D/A PROJECT: 504-01-001



WATERTOWN ARSENAL
WATERTOWN 72, MASS.

Armor-Piercing
Ammunition

# ARMOR-PIERCING SHOT PROCESSED FROM MOLYBDENUM BEARING TUNGSTEN CARBIDE

Technical Report No. WAL TR 241/1

By

C. A. Riddle

March 1959

O.O. Project: TW-426, Supporting Research on Armor-Piercing Projectiles
D/A Project: 504-01-001



WATERTOWN ARSENAL
WATERTOWN 72, MASS

WATERTOWN ARSENAL LABORATORIES

TITLE

ARMOR PIERCING SHOT PROCESSED FROM MOLYBDENUM BEARING TUNGSTEN CARBIDE

ABSTRACT

The results of limited ballistic testing with scale model 12% cobalt bonded tungsten carbide cores, processed from low-grade western ores containing molybdenum, are presented. From the data obtained it is concluded that cores containing residual molybdenum, which are manufactured from these ores, are equivalent in terminal ballistic performance to previously studied cores manufactured from high purity tungsten carbide.

C. A. Riddle
C. A. RIDDLE
Engineering Technician

APPROVED:

J. F. Sullivan
J. F. SULLIVAN
Director
Watertown Arsenal Laboratories

REPORT APPROVED
Date- 14 Apr 59
WAL Board of Review
Chairman- [illegible]

## INTRODUCTION

In the production of tungsten for the tungsten carbide cutting tool industry, high purity material is employed, the presence of small amounts of impurities, particularly molybdenum, being considered adverse to maximum tool life and performance. Because of this, it has long been considered necessary to employ the same type of high quality, high purity material in tungsten carbide armor-piercing projectiles. The use of such material requires the use of high grade tungsten ores, and when lower grade ores are employed requires additional and costly operations in processing to remove residual impurities. In order to determine whether or not tungsten carbide manufactured from molybdenum contaminated tungsten would be satisfactory for use in armor piercing shot, scale model tests were conducted with tungsten carbide having molybdenum intentionally added.[1] Since the results of these tests were encouraging, the obvious step was to perform tests with cores processed from western scheelite-molybdenite ores without separating the residual molybdenum. This report covers the results of this series of ballistic tests.

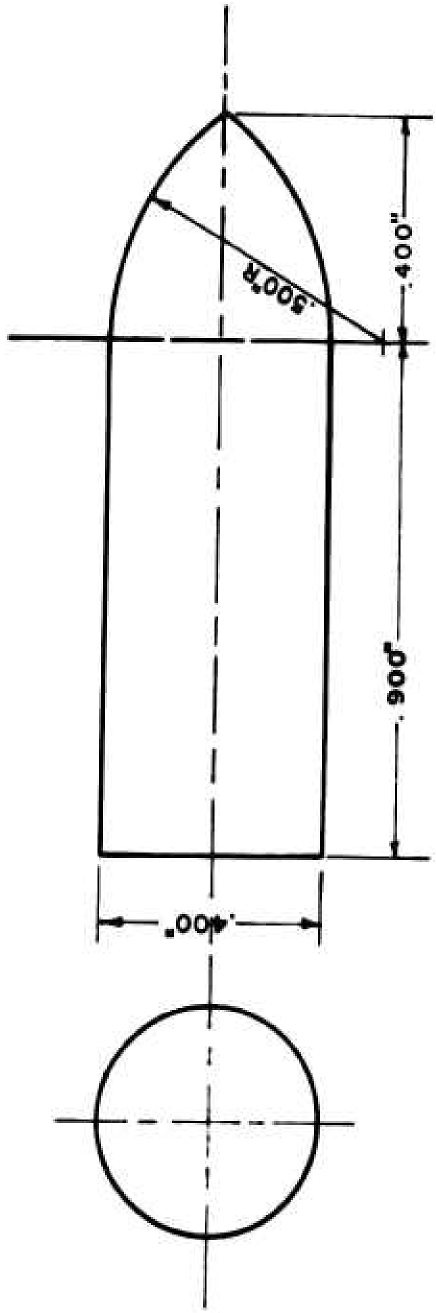
## MATERIALS AND TEST PROCEDURE

The cores employed in this study were of the same contour as WC cores employed in all previous scale model terminal ballistic studies of the effect of core composition on penetration performance. Illustrated in Figure 1 are the dimensions of the cores which were manufactured by Kennametal, Incorporated, of Latrobe, Pennsylvania, by cold pressing and sintering techniques from their composition WS12. This composition is reduced from low grade western ores without the removal of Mo and results in a product of the following composition after the tungsten is carburized and the binder is added:

| WC | Co | Mo |
|---|---|---|
| 87.4% | 12% | 0.6% |

A molybdenum carbide is formed during carburizing of the tungsten powder, providing a final structure containing tungsten carbide, molybdenum carbide, and cobalt.

Rockwell "A" hardness readings taken on a cross-section of one core were very uniform and averaged 87.2, which is comparable to the hardness of high purity tungsten carbide cores having a 12% cobalt binder content. Microscopic examination revealed a structure of WC grains 3-5 microns in size with occasional grains 6 microns in size. The cobalt binder was uniformly distributed about the WC grains. At a magnification of X200, unetched the porosity rating of the cores was determined as ASTM-C1 (indicating a small amount of undissolved or excess carbon) which is considered adequate for good quality material. Representative microstructures are shown in Figure 2.




TOLERANCES ± .005"

CALIBER .40 TUNGSTEN CARBIDE CORE

Wtn. 639-14,879

FIGURE 1

X200

UNETCHED

X1500

ETCHED

MICROSTRUCTURE OF CALIBER .40, 87.4WC. 12.0Co, 0.6Mo CORES
(ETCHANT POTASSIUM FERRICYANIDE)

Wtn. 639-16,656

FIGURE 2

Three different thicknesses of rolled homogeneous steel armor, 0.75", 1.0", and 1.5", heat treated to 285-311 BHN, were employed in the ballistic tests.[2] The plates were mounted in a holder placed 30 feet from the gun muzzle with a pair of Watertown Arsenal Laboratories type printed grid circuits spaced ten feet apart at the center of the gun-to-target distance. The first printed grid actuates, and the second grid arrests a 400KC Potter Counter-Chronograph when the projectile passes through. By means of the distance-time relationship, the projectile velocity is readily determined. Corrections for velocity loss from the second grid to the target are not employed since comparisons of penetration performance of scale model WC cores examined in the past have been made with the same gun-to-target and triggering grid distances. Performance of projectiles are then determined relative to a velocity obtained with a standard method and test procedure.

The projectiles were mounted in plastic discarding carriers and fired from a caliber 0.60 rifled gun tube. The velocities were controlled by adjusting the propellant charge weight for each round to achieve both complete and partial p.netrations of the target for the determination of protection ballistic limits.* In one instance, 1.00" at 30° obliquity, a zone of mixed results was encountered; i.e., partial penetrations of the armor were obtained at velocities above the lowest complete penetration. For computing this ballistic limit, the following equation was employed:

$$V_{50}\ PBL = \frac{\Sigma V + K(NP - NC)}{NP + NC}$$

where $V_{50}\ PBL$ = the velocity at which there exists a 50% probability that the projectile will achieve a complete penetration of the armor according to the complete penetration criteria employed in determining protection ballistic limits,

and $K = \frac{V_{HP} - V_{LC}}{2}$

$V_{HP}$ = highest velocity resulting in partial penetration

$V_{LC}$ = lowest velocity resulting in complete penetration

$V_{HP} - V_{LC}$ = zone of mixed results

$\Sigma$ = sum of velocities in zone of mixed results including $V_{HP}$ and $V_{LC}$

$NP$ = number of partial penetrations within zone of mixed results including $V_{HP}$

$NC$ = number of complete penetrations within zone of mixed results including $V_{LC}$.

---

*Defined as the arithmetical mean of the lowest velocity to result in a complete penetration and the highest velocity to result in a partial penetration when these velocities are within 150 ft/sec of each other. Complete penetrations are determined by means of a .020" thick dural sheet placed approximately 3" behind the armor.

All rounds employed in the determination of ballistic limits impacted at least three calibers apart and at least three calibers from the nearest plate edge, and were not employed in ballistic limit determinations if any visible yaw was observed on the triggering grids.

## RESULTS AND DISCUSSION

The ballistic limits obtained against the target conditions tested are presented below and compared with results of previous firings with carburized WC cores known to be of very good ballistic quality (see Reference 2).

### COMPARISON OF PROTECTION BALLISTIC LIMITS OF CALIBER .40WC CORES AGAINST ROLLED HOMOGENEOUS STEEL ARMOR

Target and Obliquity

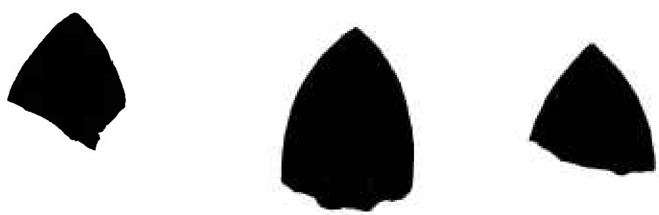
| CORE TYPE | .75" at 45° | .75" at 60° | 1.00" at 30° | 1.00" at 45° | 1.50" at 0° |
|---|---|---|---|---|---|
| 88%WC + 12%Co* | 3180 | 4065 | 2405 | 3670 | 3095 |
| 87.4%WC + 12%Co + 0.6%Mo | 3035 | 4035 | 2585 | 3695 | 2990 |

It is readily apparent that the cores processed from molybdenum contaminated ores are equivalent to the higher purity WC cores in terminal ballistic performance. The widest variation in the ballistic limit occurs against the 1.00" target oriented at 30° obliquity and is 180 ft/sec higher for the cores containing Mo. This velocity spread is within the reproducibility limits of the ballistic limit (see Reference 2). Also, against this target condition cores of good quality penetrate with intact ogive sections whereas cores of lower quality exhibit complete shatter of the ogive at velocities below the ballistic limit and achieve penetration at higher velocities. Illustrated in Figure 3 are recovered projectile fragments from complete penetrations of this target condition which show the ogives to be intact with the degree of shatter being slightly greater than observed for good quality WC-Co cores of the same contour (also shown in Figure 3). Against all other target conditions evaluated projectiles shatter at velocities below the ballistic limit regardless of core quality.

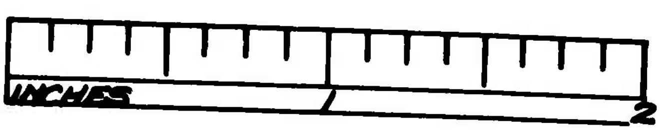
In summary, the terminal performance of the Mo bearing cores is equivalent to the performance of the cores known to be of good quality against the target conditions where projectile shatter occurs below the ballistic limit, and defeat the 1.00" at 30° target at a velocity comparable to the good quality cores. It, therefore, can be assumed that the presence of small amounts of molybdenum in WC employed for scale model armor-piercing projectiles have no detrimental effect on terminal ballistic behavior providing that adequate controls during processing are maintained to insure proper grain size and minimum porosity in the finished product.

**Previously reported data (see Reference 2).*

88%WC + 12%Co



87.4%WC + 12%Co + 0.6%Mo




COMPARISON OF TYPICAL OGIVE FRAGMENTS RECOVERED AFTER TESTING EXPERIMENTAL CALIBER .40 TUNGSTEN CARBIDE CORES AGAINST 1.00" STEEL ARMOR AT 30° OBLIQUITY

Wtn. 751-2389

FIGURE 3

In the event that it again becomes necessary to employ tungsten carbide-cored ammunition during a national emergency, savings to the Government may be realized by utilizing scheelite-molybdenite ores, encountered in some of our western states, without the necessity of separating the molybdenite. The supplies of higher grade ores will then be unaffected by the manufacture of armor piercing shot and the need for employing low grade purified ores for tungsten carbide tools will be alleviated.

Recent innovations in the ore reduction process in obtaining tungsten made it possible to obtain tungsten carbide directly from the ore. The resulting product, a crystalline tungsten carbide, is less pure than tungsten carbide obtained by reduction of tungsten from the ore and carburizing to form WC. Ballistic studies have been conducted with scale model armor-piercing cores made from both carburized and crystalline WC containing both iron and cobalt as the binder phase.[1,3,4] It was demonstrated that crystalline WC cores with either Co or Fe binders exhibit performance equivalent to carburized WC cores with the same binders, provided the binder content is less than about 12% by weight and porosity in the cores is not excessive. The use of crystalline tungsten carbide manufactured from molybdenum bearing ores, for armor piercing shot, will effect additional reductions by the elimination of still further processing requirements. With this consideration in mind, scale model cores manufactured from low grade ores are being procured for additional ballistic studies. The results of these tests will be reported when testing is completed.

## REFERENCES


1. RIDDLE, C. A., "Study of Crystalline Tungsten Carbide Containing Iron as the Binder Phase for Use in Armor Piercing Shot," Report No. WAL TR 710/1082, April 1958.

2. ABBOTT, K. H., "Effect of Composition on the Terminal Ballistic Performance of Scale Model and Full Scale Tungsten Carbide Cores Containing Cobalt as the Binder Phase" (U), Report No. WAL 762/675(c), March 1956.

3. ABBOTT, K. H., "Terminal Ballistic Comparison of Scale Model Tungsten Carbide Cores Containing Cobalt and Iron as the Binder Phase" (U), Report No.WAL 762/677(c), June 1956.

4. ABBOTT, K. H., "Study of Crystalline Tungsten Carbide for Armor Piercing Shot," Report No. WAL 762/681, May 1957.

AD 211692 Accession No.

Watertown Arsenal Laboratories, Watertown 72, Mass.
ARMOR-PIERCING SHOT PROCESSED FROM THE MOLYBDENUM BEARING TUNGSTEN CARBIDE - C. A. Riddle

Report No. WAL TR 241/1, Mar 1959, 9 pp - illus, OO Proj TW-426, DA Proj 504-01-001, Unclassified Report

The results of limited ballistic testing with scale model 12% cobalt bonded tungsten carbide cores, processed from low-grade western ores containing molybdenum, are presented. From the data obtained it is concluded that cores containing residual molybdenum, which are manufactured from these ores, are equivalent in terminal ballistic performance to previously studied cores manufactured from high purity tungsten carbide.

LIMITED DISTRIBUTION

UNCLASSIFIED

1. Armor-Piercing Ammunition

I. Riddle, C. A.

AD 211692 Accession No.

Watertown Arsenal Laboratories, Watertown 72, Mass.
ARMOR-PIERCING SHOT PROCESSED FROM THE MOLYBDENUM BEARING TUNGSTEN CARBIDE - C. A. Riddle

Report No. WAL TR 241/1, Mar 1959, 9 pp - illus, OO Proj TW-426, DA Proj 504-01-001, Unclassified Report

The results of limited ballistic testing with scale model 12% cobalt bonded tungsten carbide cores, processed from low-grade western ores containing molybdenum, are presented. From the data obtained it is concluded that cores containing residual molybdenum, which are manufactured from these ores, are equivalent in terminal ballistic performance to previously studied cores manufactured from high purity tungsten carbide.

LIMITED DISTRIBUTION

UNCLASSIFIED

1. Armor-Piercing Ammunition

I. Riddle, C. A.

AD 211692 Accession No.

Watertown Arsenal Laboratories, Watertown 72, Mass.
ARMOR-PIERCING SHOT PROCESSED FROM THE MOLYBDENUM BEARING TUNGSTEN CARBIDE - C. A. Riddle

Report No. WAL TR 241/1, Mar 1959, 9 pp - illus, OO Proj TW-426, DA Proj 504-01-001, Unclassified Report

The results of limited ballistic testing with scale model 12% cobalt bonded tungsten carbide cores, processed from low-grade western ores containing molybdenum, are presented. From the data obtained it is concluded that cores containing residual molybdenum, which are manufactured from these ores, are equivalent in terminal ballistic performance to previously studied cores manufactured from high purity tungsten carbide .

LIMITED DISTRIBUTION

UNCLASSIFIED

1. Armor-Piercing Ammunition

I. Riddle, C. A.

AD 211692 Accession No.

Watertown Arsenal Laboratories, Watertown 72, Mass.
ARMOR-PIERCING SHOT PROCESSED FROM THE MOLYBDENUM BEARING TUNGSTEN CARBIDE - C. A. Riddle

Report No. WAL TR 241/1, Mar 1959, 9 pp - illus, OO Proj TW-426, DA Proj 504-01-001, Unclassified Report

The results of limited ballistic testing with scale model 12% cobalt bonded tungsten carbide cores, processed from low-grade western ores containing molybdenum, are presented. From the data obtained it is concluded that cores containing residual molybdenum, which are manufactured from these ores, are equivalent in terminal ballistic performance to previously studied cores manufactured from high purity tungsten carbide.

LIMITED DISTRIBUTION

UNCLASSIFIED

1. Armor-Piercing Ammunition

I. Riddle, C. A.

WATERTOWN ARSENAL
TECHNICAL REPORT DISTRIBUTION

Report No.: WAL TR 241/1 Title: "Armor-Piercing Shot Processed from Molybdenum Bearing Tungsten Carbide"

| To: | No. of Copies |
|---|---|
| Commanding Officer<br>Watertown Arsenal<br>Watertown 72, Mass.<br>Attn: Tech. Ref. Section | 5 |
| Rodman Laboratory | 1 |
| Author | 1 |
| Office, Chief of Ordnance<br>Department of the Army<br>Washington 25, D. C.<br>Attn: ORDIR - Artillery | 1 |
| ORDIM - Ammunition | 1 |
| ORDTB - Research Branch | 1 |
| ORDTA - Ammunition Dev. | 2 |
| ORDTT - Tank-Automotive | 1 |
| Commanding General<br>Frankford Arsenal<br>Philadelphia 37, Pa<br>Attn: Pitman-Dunn Labs. | 1 |
| Commanding General<br>Picatinny Arsenal<br>Dover, New Jersey<br>Attn: FREL | 2 |
| Commanding Officer<br>Springfield Armory<br>Springfield 1, Mass.<br>Attn: ORDBD-TX | 1 |
| Commanding Officer<br>Detroit Arsenal<br>Center Line, Michigan<br>Attn: ORDMX-AL | 1 |
| Commanding General<br>Aberdeen Proving Ground<br>Aberdeen, Maryland<br>Attn: Ballistic Res. Labs. | 1 |
| Development & Proof Services | 1 |

Trans date: 4/14/59

| To: | No. of Copies |
|---|---|
| Commanding General<br>Ordnance Weapons Command<br>Rock Island, Illinois<br>Attn: ORDOW-TX | 2 |
| Chief, Bureau of Ordnance<br>Department of the Navy<br>Washington 25, D. C.<br>Attn: Re-3 | 1 |
| Commander<br>Naval Proving Ground<br>Dahlgren, Virginia<br>Attn: A&P Labs. | 1 |
| Commanding Officer<br>Office of Ordnance Research<br>Box CM, Duke Station<br>Durham, N. C. | 1 |
| Commanding General<br>Ordnance Ammunition Command<br>Joliet, Illinois<br>Attn: ORDLY-AR-AR, Lt. Myers | 1 |
| Commander<br>Armed Services Tech. Info. Agency<br>Arlington Hall Station<br>Arlington 12, Virginia<br>Attn: TIPDR | 5 |
| Commanding Officer<br>Diamond Ordnance Fuze Labs.<br>Washington 25, D. C.<br>Attn: Tech. Reference Section<br>ORDTL 06.33 | 1 |

TOTAL COPIES DISTRIBUTED --- 32

No. of copies prepared 50
No. of copies remaining 18