

ARMY RESEARCH LABORATORY



Hot-Metal Simulating Igniter for In-Bed Thermal Initiation of Granular Charges

by Stephen L. Howard

ARL-TR-5276

August 2010

NOTICES

Disclaimers

The findings in this report are not to be construed as an official Department of the Army position unless so designated by other authorized documents.

Citation of manufacturer's or trade names does not constitute an official endorsement or approval of the use thereof.

Destroy this report when it is no longer needed. Do not return it to the originator.

Army Research Laboratory

Aberdeen Proving Ground, MD 21005-5066

ARL-TR-5276

August 2010

Hot-Metal Simulating Igniter for In-Bed Thermal Initiation of Granular Charges

Stephen L. Howard
Weapons and Materials Research Directorate, ARL

| REPORT DOCUMENTATION PAGE | | | <i>Form Approved</i> OMB No. 0704-0188 | | |
|--|------------------------------------|-------------------------------------|--|---|---|
| Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing the burden, to Department of Defense, Washington Headquarters Services, Directorate for Information Operations and Reports (0704-0188), 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number. PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS. | | | | | |
| 1. REPORT DATE (DD-MM-YYYY) August 2010 | | 2. REPORT TYPE Final | | 3. DATES COVERED (From - To) June–August 2009 | |
| 4. TITLE AND SUBTITLE Hot-Metal Simulating Igniter for In-Bed Thermal Initiation of Granular Charges | | | 5a. CONTRACT NUMBER | | |
| | | | 5b. GRANT NUMBER | | |
| | | | 5c. PROGRAM ELEMENT NUMBER | | |
| 6. AUTHOR(S) Stephen L. Howard | | | 5d. PROJECT NUMBER 622618.H8000 | | |
| | | | 5e. TASK NUMBER | | |
| | | | 5f. WORK UNIT NUMBER | | |
| 7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) U.S. Army Research Laboratory ATTN: RDRL-WML-D Aberdeen Proving Ground, MD 21005-5066 | | | 8. PERFORMING ORGANIZATION REPORT NUMBER ARL-TR-5276 | | |
| 9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) | | | 10. SPONSOR/MONITOR'S ACRONYM(S) | | |
| | | | 11. SPONSOR/MONITOR'S REPORT NUMBER(S) | | |
| 12. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution is unlimited. | | | | | |
| 13. SUPPLEMENTARY NOTES | | | | | |
| 14. ABSTRACT An igniter simulating the effects of penetrating hot-metal fragments into a granular propellant bed was designed, constructed, and tested. This primer was designed to facilitate the characterization of the ignition and early-time combustion processes in a large-caliber propellant charge confined in a closed chamber which was initiated by an in-bed hot ignition source. The primer was used to simulate the situation when charge ignition occurs by a hot fragment that penetrated the chamber wall and remained within the propellant bed. Experiments showed that an igniter composed of micron-sized particle thermite powder (Al/Fe2O3) surrounded by ball powder propellant contained in a cloth tube initiated simultaneously by multiple electrical matches was capable of providing proper ignition stimulus to the propellant charge. | | | | | |
| 15. SUBJECT TERMS ballistic simulator, primers, MIC, thermite, shipping container | | | | | |
| 16. SECURITY CLASSIFICATION OF: | | | 17. LIMITATION OF ABSTRACT | 18. NUMBER OF PAGES | 19a. NAME OF RESPONSIBLE PERSON Stephen L. Howard |
| a. REPORT Unclassified | b. ABSTRACT Unclassified | c. THIS PAGE Unclassified | | | UU |

Contents

| | |
|------------------------------------|-----------|
| List of Figures | iv |
| Acknowledgments | v |
| 1. Introduction | 1 |
| 2. Experimental Development | 1 |
| 3. Results and Discussion | 3 |
| 4. Summary | 4 |
| Distribution List | 5 |

List of Figures

| | |
|---|---|
| Figure 1. Igniter schematic and photo..... | 2 |
| Figure 2. Flame development of igniter in open air..... | 4 |

Acknowledgments

The author would like to express his appreciation to Dr. Lang-Mann Chang for his assistance and direction.

INTENTIONALLY LEFT BLANK.

1. Introduction

There are a number of current efforts in the U.S. Military aimed at achieving insensitive munitions compliance. One such effort is the development of venting technologies for metal cartridge cases and metal storage/shipping containers of large-caliber propellant charges. The design goal is to reduce or eliminate a violent reaction of the propellant charge when it is subjected to extraordinary stimuli such as intense heat, impact, or shock.

For this purpose, a low-impact, hot-metal igniter was designed, constructed, and tested to prove its adequacy in providing the stimulus akin to that seen when a hot-metal fragment penetrates and reposes in a large-caliber propelling charge inside of a standard shipping container. Design metrics included ignition delay, consistent ignition stimulus over the simulated penetration track of the simulated hot-metal fragment, and temperature of the reacting ignition materials that would be comparable to the myriad of oxidizing metal particles formed upon impact of the fast-moving fragment with the steel shipping container. After the completion of this design study, a low-impact, hot-metal igniter was used in a large-caliber propelling charge shipping container simulator with exceptional success.¹

2. Experimental Development

Prior art in the simulating of the penetrating and reposing of a hot-metal fragment in a propelling charge used a thermite igniter with commercial-off-the-shelf (COTS) thermite powder.² This igniter was very slow (tenths of a second) and non-uniform in providing spatially consistent ignition stimulus. At the time of the current development, the COTS thermite powder was not available and so a replacement material was designed. The replacement material still used the primary components of the COTS material, but the particle size was reduced and the mixing process was modified.

A spherical aluminum powder with an average particle size of 3.0–4.5 μm with a 97.5% metal content was mixed with an iron oxide (Fe_2O_3) powder with an average particle size of –325 mesh ($<44 \mu\text{m}$). The powders were mixed gently in proportions of approximately 1:3 (Al/ Fe_2O_3) on a mass basis. Ethyl alcohol solvent was added to wet the paste and the mixture was placed in an ultrasonic bath for 30 min. The ultrasonic bath both mixed the powders on the

¹Chang, L. M. *The Response of a Large-caliber Granular Charge in Confinement to an In-bed Thermal Initiation*; ARL-CR-646; U.S. Army Research Laboratory: Aberdeen Proving Ground, MD, 2010.

²Birk, A.; Boyle, V.; Chang, L. M. *The Response of MACS Modules in Shipping Configuration to a Peripheral In-bed Thermal Initiation*; ARL-TR-4013; U.S. Army Research Laboratory: Aberdeen Proving Ground, MD, 2007.

macro scale and tended to help “pack” the Fe_2O_3 particles around the aluminum particles. The solvent was then removed by slow drying.

This processing should have been sufficient, but since prior art used BKNO_3 powder, it was requested that a fine powder of BKNO_3 be added to the mixture to the 10% level. The BKNO_3 had been added to prior art mixtures to facilitate and accelerate the initiation of the thermite reaction. However, the change in particle sizes and in processing of the thermite mixture should have been sufficient for the requisite initiation.

With the reacting thermite, the effects of the hot metal particles generated during the fragment penetration would be simulated. The next requirement of the igniter was to provide propellant ignition similar to that provided by the fast fragment plowing into the grains of the propellant bed. During the passage of the fragment through the propellant bed, a portion of the propellant grains in its path would be fractured. This “rubble” zone would be more facile to ignite and would burn faster than designed due to the greatly expanded surface area. The “rubble” zone would only exist along the passage of the penetrating fragment so the “rubble” simulant would need to be close to the thermite mixture along the simulated path of the fragment.

This effect was simulated by placing ball powder propellant (WC855 propellant) around a core of thermite powder. Since the simulator will provide data for computer models, the ball powder propellant was chosen for its easily-modeled size and known properties. The ball powder was placed in a cloth bag so that the gases produced by ignition would easily pass into the main propellant bed. The igniter was made to approximately two-thirds length of the diameter of the proposed main propellant bed (see figure 1).

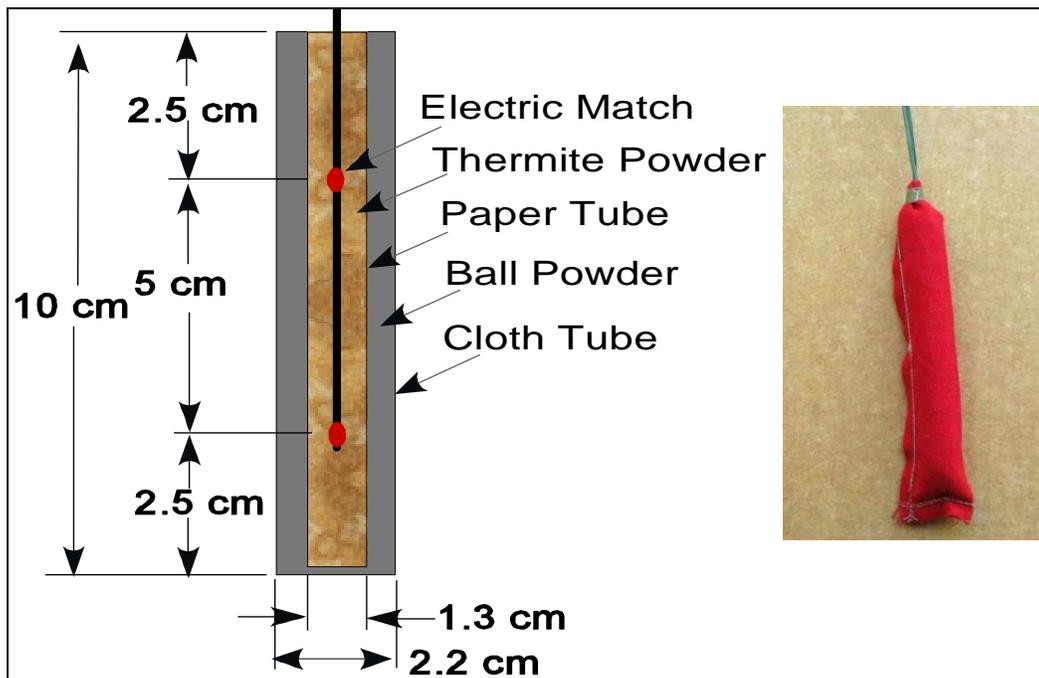


Figure 1. Igniter schematic and photo.

The thermite and the ball powder weighed 15 and 20 g, respectively. Both igniter materials were in well-defined confinement zones (paper and cloth tubes), intended to be suitable for interior ballistics modeling. Two electric matches were inserted, equally spaced, into the thermite bed for initiation of the igniter. The electric matches were wired in parallel and initiated with a 24-V, 10-ms electrical pulse (prior art used ~5 kV). While the lower end of the cloth tube was sealed, the upper end was taped tightly around the electric match lead wires. The overall size of the igniter was 10 cm in length and 2.22 cm in diameter, which properly fit into the desired main propellant charge.

High-speed video with a Phantom 5 camera was obtained in order to record the flame spreading. The framing rate was set to ~10,000 frames/s and triggered off the ignition trigger pulse.

3. Results and Discussion

It was important to ensure that the igniter was able to ignite the propellant charge within a proper delay time. Several test runs were conducted with various weights of thermite powder and ball powder to determine the necessary igniter composition. It was concluded that a total weight of 35 g (15 g of thermite powder and 20 g of ball powder) was sufficient.

Figure 2 displays a series of images obtained from the high-speed camera showing a typical sequence of the flame development in open air ignition. The test series determined that the ignition delay ranged from 10 to 15 ms (it should be noted that the ignition delay was defined to be the time at which the first visible light was seen after application of the firing voltage). Within 4 ms of first light, the illuminated area had expanded widely and the light became very bright, demonstrating a very high temperature region. Numerous burning particles, ejected from the igniter, were seen. The illumination was sustained for more than 30 ms.

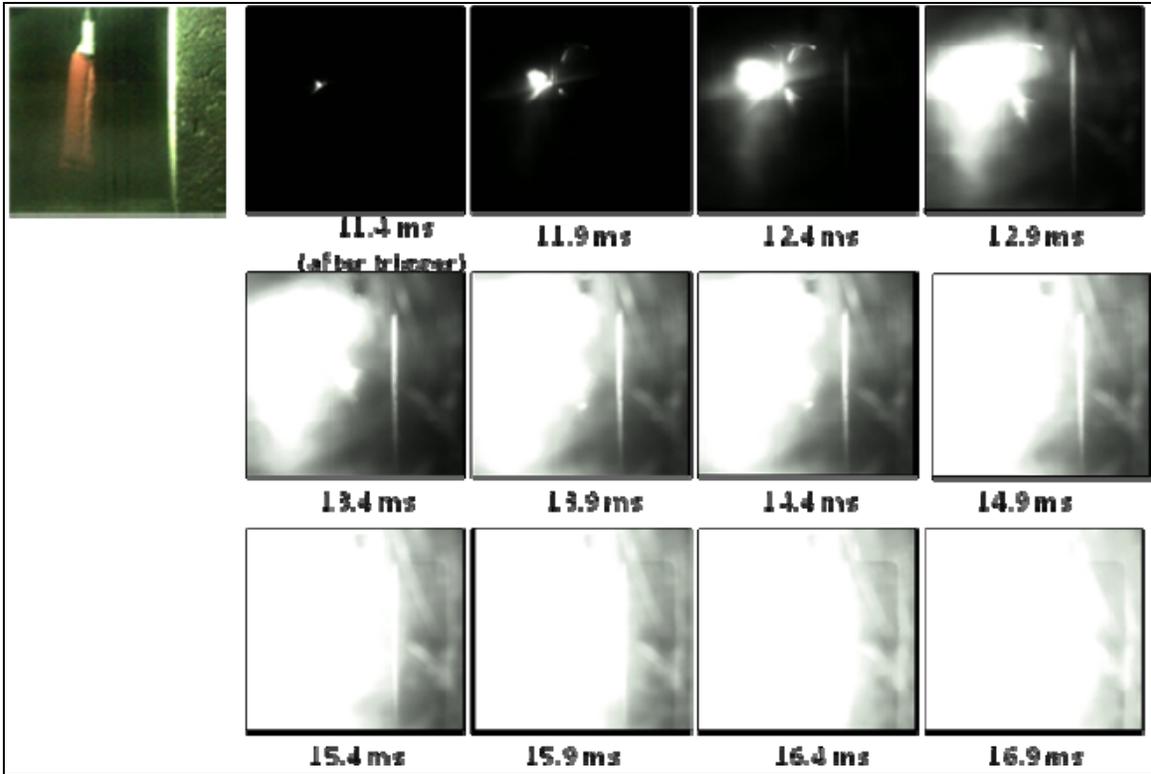


Figure 2. Flame development of igniter in open air.

4. Summary

An igniter suitable for hot-metal fragment impact simulation on a large-caliber propellant bed contained in a shipping container was design, constructed, and tested. The combination of fast thermite and ball powder propellant zones in the igniter provided for fast ignition of the main propellant bed in similar fashion as a fast hot-metal fragment that entered the shipping container creating hot-metal particles and a propellant “rubble” zone.

The igniter was designed for, and demonstrated, nearly symmetric ignition about its z-axis, thus overcoming prior art. The ignition delay was more than an order of magnitude shorter than prior art, thus reducing the potential for igniter-dependant effects.

NO. OF
COPIES ORGANIZATION

1 DEFENSE TECHNICAL
(PDF INFORMATION CTR
only) DTIC OCA
8725 JOHN J KINGMAN RD
STE 0944
FORT BELVOIR VA 22060-6218

1 DIRECTOR
US ARMY RESEARCH LAB
IMNE ALC HRR
2800 POWDER MILL RD
ADELPHI MD 20783-1197

1 DIRECTOR
US ARMY RESEARCH LAB
RDRL CIM L
2800 POWDER MILL RD
ADELPHI MD 20783-1197

1 DIRECTOR
US ARMY RESEARCH LAB
RDRL CIM P
2800 POWDER MILL RD
ADELPHI MD 20783-1197

1 DIRECTOR
US ARMY RESEARCH LAB
RDRL D
2800 POWDER MILL RD
ADELPHI MD 20783-1197

ABERDEEN PROVING GROUND

1 DIR USARL
RDRL CIM G (BLDG 4600)

| <u>NO. OF COPIES</u> | <u>ORGANIZATION</u> |
|--------------------------|---|
| 1 | US ARMY ARDEC RDAR MEM L M DONADIO BLDG 65S PICATINNY ARSENAL NJ 07806-5000 |
| 2 | US ARMY ARDEC RDAR MEE W P HUI D PARK BLDG 382 PICATINNY ARSENAL NJ 07806-5000 |
| 1 | US ARMY ARDEC SFAE AMO CAS J RUTKOWSKI BLDG 171M PICATINNY ARSENAL NJ 07806-5000 |
| 1 | US ARMY ARDEC AMSRD AAR AEE W J O'REILLY BLDG 328 PICATINNY ARSENAL NJ 07806-5000 |
| 1 | REDECOM ARDEC AMSRD AAR AEM J J HIRLINGER BLDG 65N PICATINNY ARSENAL NJ 07806-5000 |
| 1 | PM TMAS SFAE ASM TMA MS R KOWALSKI BLDG 171A PICATINNY ARSENAL NJ 07806-5000 |
| 1 | ST MARKS POWDER GENERAL DYNAMICS R PULVER 7121 COASTAL HWY CRAWFORDVILLE FL 32327 |

| <u>NO. OF COPIES</u> | <u>ORGANIZATION</u> |
|--------------------------|---|
| 1 | ST MARKS POWDER GENERAL DYNAMICS J DRUMMOND 7121 COASTAL HWY CRAWFORDVILLE FL 32327 |
| 1 | ST MARKS POWDER GENERAL DYNAMICS J HOWARD 7121 COASTAL HWY CRAWFORDVILLE FL 32327 |
| 1 | RADFORD ARMY AMMO PLANT W WERRELL PO BOX 1 RT 114 RADFORD VA 24143 |
| 2 | ATK C AAKHUS M JANTSCHER MN07-LW54 4700 NATHAN LN N PLYMOUTH MN 55442 |
| 1 | ATK LAKE CITY K ENLOW PO BOX 1000 INDEPENDENCE MO 64051-1000 |
| | <u>ABERDEEN PROVING GROUND</u> |
| 13 | DIR USARL RDRL WM J SMITH RDRL WML E B GUIDOS RDRL WML D S HOWARD (3 CPS) A BRANT R BEYER L M CHANG J COLBURN P CONROY M NUSCA J SCHMIDT A WILLIAMS |