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THE HOT FRAGMENT CONDUCTIVE IGNITION TEST FOR SCREENING LOVA PROPELLANTS

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The Hot Fragment Conductive Ignition Test for Screening LOVA Propellants

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Abstract

The Hot Fragment Conductive Ignition (HFCI) Test was set up to determine the relative ignitability of propellant grains in response to hot fragments of different masses heated to different temperatures. The minimum temperature at which the propellant ignites gives a measure of the ignitability of the propellant. The test is a rapid screening to evaluate the vulnerability of propellant to an external aggressive stimulus such as spall attack. A number of different types of propellants including CAB/RDX propellants, nitrocellulose (NC)-based propellants and HTPB/RDX composite propellants were tested. The HTPB/RDX and NC-based propellants were found to be more vulnerable than the CAB/RDX propellants.

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Contents

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1. *Introduction*

The vulnerability of the ammunition carried on board may determine the survivability of the weapon system. In armoured systems, especially tanks, the primary threat to survivability is the ignition of propellant by spall fragments of various sizes generated from the metal armour following penetrative or non-penetrative impact. The mechanism for propellant ignition is a conductive thermal process (ref 1).

The Hot Fragment Conductive Ignition (HFCI) Test, developed at the U.S. Ballistics Research Laboratory (BRL) (refs 1,2), is a laboratory tool to evaluate the relative susceptibility of low vulnerability (LOVA) propellant formulations to conductive ignition. LOVA ammunitions are being sought through the development of new propellants that can sustain external *aggressive stimuli*, including impact by spall particles. In this effort, the HFCI test provides a means of rapidly screening new formulations available in small quantities prior to decision to scaling up for further testing. The characterisation of a propellant typically requires 200-250 grams of sample. Results from the HFCI test have been used as a measure of the propellant ignitability (ref 3) as determined by the minimum ignition temperature for particular fragment masses.

In the HFCI test, a steel ball of known mass, heated to a known temperature in a tube furnace, is dropped into a bed of the propellant grains to be tested. The response of the propellant to the hot ball is determined by observing whether ignition occurred. Ignition is defined (ref 3) as a self-sustaining decomposition of the propellant sample.

In a typical test sequence, the temperature of the ball is increased or decreased in 25°C increments. The test is repeated with different masses until a minimum ignition temperature for each mass is determined, which is accurate in this case to ±13°C. The higher the ignition temperature and/or the bigger the mass fragment required for ignition, the more "LOVA" the propellant is. This Hot Fragment Conductive Ignition Test may be considered as more simple but better defined than the related test in which a shaped charge jet generates spall fragments directing at filled cartridges.

As part of an RAN sponsored task to develop a concept demonstrator LOVA 5"/54 propelling charge, the HFCI test was established at EOD-S. This report describes the test equipment and results for some representative LOVA and conventional propellants.

2. *Experimental*

2.1 Equipment

The design and construction of the HFCI test apparatus at EOD-Salisbury was based upon a schematic diagram and a brief description of the BRL equipment (ref 2). The BRL test set-up consisted of a vertically mounted tube furnace which is capable of maintaining temperatures up to 1093°C. The furnace is used to heat the steel mass fragments held in place by means of an electromagnet constructed from a length of 6mm diameter steel rod connected to a solenoid and a power supply. The test temperature was measured by means of a type K chromel-alumel thermocouple located close to the test fragment and recorded on a chart recorder. Temperature control was independent of the temperature measurement. The sample containers were 20 x 40 mm glass vials and the fragments were standard ball bearings. The fragment masses used at BRL were 0.13, 0.25, 0.43, 0.69, 1.03, 2.03 and 5.58 grams.

Sample were prepared at BRL by stacking propellant grains vertically to a depth of at least 20 mm within the glass vial. No spaces were left between grains that would allow the passage of the fragment. The amount of sample was not critical except that the propellant bed was deep enough to prevent the fragment from melting its way to the bottom of the vial.

The equipment at EOD-S (fig 1) consisted of a vertically mounted "Carbolite" tube-furnace. The quartz furnace tube, which has an internal diameter of 30 mm, was heated by four silicon carbide elements that permit the temperature to be changed rapidly. The temperature of the furnace was controlled in the range 20-1200°C by means of a temperature controller.

Instead of the electromagnetic system for holding and releasing the test fragments used by BRL, at EOD-S a system using vacuum was constructed. A length of silica tubing approximately 4 mm in diameter was suspended from a clamp above the furnace tube and extended down into it so that the lower end is positioned centrally within the furnace. The end of the silica tubing was ground square and the internal diameter slightly bevelled to provide a good contact with the steel balls. The clamp which supports the silica tubing was attached to a support stand by means of a rack and pinion mechanism which allowed the tube to be raised and lowered rapidly and smoothly within the furnace tube. This mechanism allows the operator to prepare the apparatus for a test with only a small temperature disturbance to the whole furnace. As a result, the test fragment and the furnace can reach the test temperature as quickly as possible. The end of the silica tubing outside the furnace was attached to a vacuum system by way of a two-way valve.

A heat resistant graphite plug around the silica tubing blocked the furnace tube at the upper end to prevent convection currents within the furnace tube. A type K chromel-alumel thermocouple was mounted on the silica tube as close to the lower end as was possible and was connected to the temperature controller. This system allows direct temperature control of the furnace as the voltage generated by the thermocouple was used to control the current output of the controller to the heating elements of the furnace. The fragment temperature was read from the meter incorporated in the temperature controller.

Fragments in the form of bearing balls of masses 0.13, 0.25, 0.44, 0.88, 1.05, 2.05 and 3.52 grams were used to determine ignition temperatures. These fragment sizes were chosen because of their ready availability and, except for those that weighed 0.88 and 3.52 grams, corresponded to those used by BRL.

Propellant samples were placed in small glass beakers of suitable sizes placed at the lower end of the furnace tube. The method of packing the propellant bed was identical with that used in the BRL tests. This resulted in sample weights of 10 to 15 grams per test. The sample weight depended upon the nature of the sample, its size and shape and whether it melted on contact with the hot fragment. If a propellant melted the sample bed was made deeper than for those which did not.

The tests were performed inside an efficient fume cupboard because of the nature and large quantity of fumes generated.

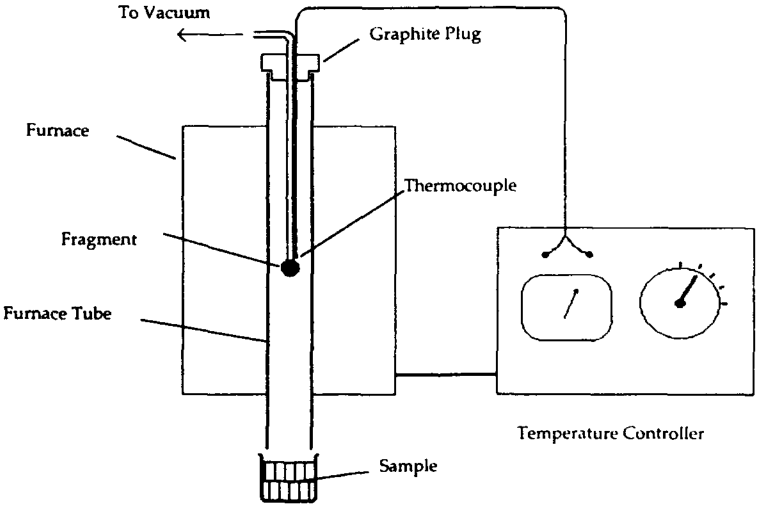

Figure 1: *Hot Fragment Conductive Ignition Test Apparatus*

2.2 *Procedure*

Tests were carried out starting with the largest ball and the lowest temperature.

With the silica tube lowered, the furnace was switched on and heated up to a temperature believed to be below the ignition temperature of the test propellant. The silica tube was raised so that the lower end cleared the top of the furnace tube and the steel ball was offered up to the tube end while simultaneously operating the vacuum valve in order to fix the ball to the end of the tube. The tube was then lowered and the temperature of the furnace and ball allowed to stabilise. When the desired temperature had been reached the vacuum was released and the ball allowed to fall onto a bed of the propellant. Particular care had to be taken to pack the propellant bed to prevent the smaller test fragments from falling into gaps between the propellant grains. The sample was observed from a distance until the generation of any smoke had ceased.

The test was repeated at a higher temperature for the same ball mass until the lowest temperature at which ignition occurred was determined. A positive result, ie. ignition, was indicated when the propellant decomposition was self sustaining and complete (ref 2). A test may generate quantities of smoke for a brief time but this alone was not interpreted as ignition of the sample.

The test was then repeated using progressively smaller sized balls commencing at the same test temperature as the previous positive test.

3. *Results and Discussion*

A small number of samples of experimental gun propellants were tested as well as one sample of M30 and one sample of BS-NACO propellant. The two latter propellants were tested in order to compare the results obtained at EOD with published data (refs 3,4,5). The HFCI results are given in table 1.

Table 1: *Hot Fragment Conductive Ignition Test - Minimum Ignition Temperature (°C)*

	Mass Fragment (steel ball) (g)						
Propellant	0.13	0.25	0.44	0.88	1.05	2.05	3.52
CAB/RDX Propellants							
GP1111 (XM39)	888	888	888	888	788	688	563
XM39 (ref 4)		638	763		663		
LCP-A-6603 (ref 5)	875	775			600	475	
GP1112 (BDNPA/F)	913	888	863	838	788	688	513
NC/NG/NQ and NC Propellants							
M30 RAD63574	463	388	363	338	313	288	263
M30 (ref 3)			363		338	313	288
M30 (ref 4		438	388		338		
BS-NACO Lot1809C	538	438	413	363	338	313	313
NACO (ref 3)			413		363	338	313
HTPB/RDX Propellants							
15(HTTX-AO)(65/35/0)RX	563	488	413	388	338	338	313
20(HTDNIP-AC)(65/35/0RX)	513	463	413	363	338	313	288
20(HTDNIP-AC)(20/80/0RX)	563	413	388	363	363	338	313
20(HTDNIP-AC)(0/70/30RX)	588	463	438	388	363	338	313
20(HTDNIP-AC)(0/30/70RX)	513	413	413	388	363	313	288
20(HTADDN-OA)(0/70/30RX)	488	388	363	338	338	313	288
20(HTADDN-OA)(0/70/30RX)4AN	438	363	363	338	338	313	288

3.1 *CAB/RDX Propellants*

Contact between a hot fragment and these propellants caused smoke to be evolved while the propellant melted at the point of contact. This melting caused the fragment to penetrate the propellant bed exposing and heating fresh material until the fragment temperature fell. In some instances, dependant on fragment size, this penetration distance was 1.5 to 2 cm. Only when the fragment came nearly to rest was it able to transfer sufficient energy to ignite the propellant. When ignition occurred the fragment would reheat and continue its downward path. The propellant was consumed, generally without flame, leaving little residue.

The locally made XM39 propellant (GP1111) produced results that differ from values reported elsewhere (refs 4,5). Further, results obtained from these two sources differed significantly from each other. This variance may reflect differences in the way the ignition temperature was defined and reported (see earlier), or in the sample geometry and sample arrangement in the test beaker.

Further, this difference in results may also be attributed in part to the behaviour of these materials which melt at a temperature below their ignition point. Sample geometry affected the results at low fragment mass (0.13 and 0.25g) due to the fragment occasionally falling into gaps between adjacent propellant grains. The fragment in this case was able to give up heat to the surrounding propellant as it passed without heating the propellant to its ignition temperature. Law and Rocchio (ref 2) reported that care was required when using the small fragments but found that results obtained for the 0.13 gram fragment gave a good correlation with those obtained using the Shaped Charge Jet Spall Test. Strauss (ref 4) carried out HFCI testing with only three different masses (0.25, 0.43 and 1.03g), and Kirshenbaum (ref 3) used four different mass balls (0.43, 1.03, 2.03 and 3.5g). Neither reported using a 0.13g fragment and the high temperatures required for this size fragment to ignite some types of propellant, as well as the problems described above, may mitigate against its usefulness.

The results obtained for the locally produced GP1112 which contained the energetic plasticiser bis-2,2-dinitropropyl acetal/formal (BDNPA/F) rather than the non-energetic acetyl triethyl citrate (ATEC) were comparable with those for the local XM39 propellant.

3.2 *Nitrocellulose Based Propellants*

When the nitrocellulose (NC)-based propellants (M30 and BS-NACO) were tested, the hot fragment rested at the contact point and transferred its heat to the propellant. If the fragment temperature was sufficient to cause ignition, the propellant would cause smoke at first, then it would be consumed rapidly with or without a visible flame. The ignition would then spread rapidly from grain to grain as each grain lost its structure and ignited adjoining grains.

Reasonable agreement with previously published data was obtained for the NC-propellant, i.e. BS-NACO (ref 3), and for the NC/NG/NQ propellant, i.e. M30 (refs 3,4). The single base propellant tended to produce higher ignition temperatures than did the triple base propellant.

3.3 HTPB/RDX Composite Propellants

A series of four HTPB/RDX propellants which contained ATEC and a bimodal blend of RDX selected from three lots with different particle sizes (240µm, 15-16µm and 5-6µm) were tested to examine the effect of average particle size on ignitability. Two propellants, both containing dioctyl adipate (DOA) rather than ATEC and one with 4% ammonium nitrate (AN), were also tested. Finally, a propellant with a lower binder content (15% rather than 20%) was tested. The results are summarised in Table 1.

Hot fragments coming into contact with these propellants did not cause any apparent melting. Large volumes of smoke were produced at the fragment contact point even when the material did not subsequently ignite. Upon ignition, the propellant was consumed slowly with copious amounts of smoke and only occasionally a visible flame. The burning propellant retained its structure, leaving a char similar in size and shape to the unburnt material.

Results for the series of HTPB/RDX/ATEC formulations with decreasing average RDX particle sizes showed no significant correlation between ignition temperature and particle size. Formulations containing the plasticizer ATEC performed better in the test than did similar propellants containing the plasticizer DOA. The one propellant which had a lower binder level showed higher ignition temperatures than the other DOA propellants.

4. Comparison and Recommendations

Of the different propellant types tested, CAB/RDX propellants have higher minimum ignition temperatures than NC-based and HTPB/RDX propellants. Hot fragments in contact with CAB/RDX propellant cause melting and penetration into the propellant mass. This effect does not occur in the NC and HTPB/RDX propellants and is attributable to the nature of the binder in each propellant type. The minimum ignition temperature does not depend on the nature of the plasticiser in the CAB/RDX propellants (energetic vs non-energetic).

The time required for the testing of a propellant sample using seven fragment sizes is approximately four hours. This time could be shortened by reducing the number of fragment masses if this could be done without significantly reducing the information obtained from the test. The results for all the propellants tested show a similar pattern for fragment masses greater than 1.05 grams in that the ignition temperature increased in a nearly linear way. The results from the 2.05 gram fragment could be deleted with minimal effect to the overall results. As discussed earlier, the results obtained from the 0.13 gram fragment are difficult to reproduce from test to test and this fragment size could also be deleted from the test. The use of the 0.88 gram fragment has not been reported elsewhere but its deletion from the test is not recommended until a larger number of samples are tested. These deletions would reduce the fragment masses to 0.25, 0.44, 0.88, 1.05 and 3.52 and reduce the time required for the test considerably, in some cases by a third.

Law and Rocchio (ref 2) have defined ignition for the purposes of the test as "the self-sustained burning of the propellant sample" and add that "the sample must sustain itself and burn to completion". Other authors (refs 3,4,5) have also used the above criteria and our experience with the test does not indicate that any modification to this definition is either desirable or necessary.

The HFCI test can be set up from equipment readily found in any well equipped laboratory. The test is simple to perform and can be safely conducted by one operator who is familiar with laboratory procedures and safety.

5. *Acknowledgements*

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The Hot Fragment Conductive Ignition (HFCI) Test was set up to determine the relative ignitability of propellant grains in response to hot fragments of different masses heated to different temperatures. The minimum temperature at which the propellant ignites gives a measure of the ignitability of the propellant. The test is a rapid screening to evaluate the vulnerability of propellant to an external aggressive stimulus such as spall attack. A number of different types of propellants including CAB/RDX propellants, nitrocellulose (NC)-based propellants and HTPB/RDX composite propellants were tested. The HTPB/RDX and NC-based propellants were found to be more vulnerable than the CAB/RDX propellants.

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