



Use of a Compressed Gas Gun to Investigate Response of Explosives to a Range of Initiation Stimuli

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Abstract: Low velocity impacts are a source of explosive accidents. Several different mechanisms may be concurrently responsible for the initiation. Studying the effects of low velocity, comparatively long duration, impacts on energetic materials can assist in the development of explosive safety procedures and Insensitive Munitions. Careful design of the target configuration can eliminate some of the problems associated with the original Steven tests and enable the various mechanisms such as friction, shear and pinch to be isolated from other factors. In the new configuration the impact is delivered to the explosive by a spigot driven into the target by collision from a gun launched sabot. The spigot geometry i.e. flat or hemi-spherically nosed was varied as was the surface roughness and diameter of the spigot. The rate of energy delivery was varied, by varying the mass of the sabot and its velocity. The gun, 50 mm diameter, operated in the normal atmosphere conditions, NAG. Results show that pinch may be the most critical stimulus but also that friction is more significant than shear. Examination of the target debris following an event indicated that for some materials the limited confinement arising during the firing may result in a burn to detonation condition whereas for other materials the confinement was insufficient for the DDT to occur. Further work on the sample perfection and homogeneity are planned.

Keywords: accidents, impact, initiation, explosives, energy, output

Introduction

In the past a number of costly accidents with munitions, both in peacetime and war zones has resulted in the loss of five USN warships, four ammunition

storage depots and two Soviet submarines all with significant loss of human lives.

More recent accidents during EOD work have demonstrated that there is a gap in test procedures. Operators sent out to sample failed munitions prior to disposal have variously taken chisels, screwdrivers and broom handles in conjunction with large (3 kg) hammers. In one accident a rocket motor ignited and left the chisel in the operator's skull. In Afghanistan a multinational team were trying to remove an explosive warhead from a Soviet SAM missile when an ignition occurred with a resulting deflagration or low order detonation event killing five people [1]. In these two incidents the maxim elicited by F.P. Bowden [2] "hitting a solid with a hammer or rubbing it with sandpaper is a proper experiment for a Carpenter than for a physicist" appears to have been forgotten. Nevertheless impact either by dropping munitions from modest heights or striking munitions with implements is a major source of accidental initiation in explosives and thus requires further study.

As a result of accident initiation the following series of safety tests for explosive fillings using different forms of impact have been developed in the NATO countries:

- Bullet Attack (STANAG 4241),
- Fragment Attack (STANAG 4296),
- Shaped Charge Attack (STANAG 4526),
- Sympathetic reaction (STANAG 4625).

Some of these tests are particularly applied to completed weapons in their packaging. Impact test methodologies are almost as numerous as the test houses using them and quantitative agreement between them is rare [3]. JSP 333 [4] quotes 38 separate sensitivity tests of which a number are impact in one form or another. Impact test sample size ranges from the mg level of the Rotter and Drop or Fall Hammer tests to the 200 g of the Susan and Steven tests. In the Susan test [5], the explosive, contained in a specified projectile, is fired at an armoured target using a propellant gun and in the Steven [6] test the explosive, contained in a target, is struck by a gun launched projectile. Basic principles of the Steven test and modified assembly trialled are shown in Figure 3. Computational fluid dynamic calculations on the Steven test [7] predict that ignition occurs from a variety of mechanisms and the response can be sensitive to preparation procedures. Modelling and prediction are thus difficult.

Ignition occurs in accidents as a result of hot spot generation when the rate of heat liberation is greater than the rate of heat loss. The major stimuli responsible for hot spot creation are:

- compressive effects - adiabatic heating of trapped gases and pore

collapse,

- frictional effects - both inter-crystalline and at surface boundaries,
- mechanical effects - impact, shear, tribochemical and viscous flow.

Most of the accidental ignitions occur at low velocities so that the shock wave impact mechanism is not operative. Driving a spigot into explosive samples could produce systems in which the various ignition mechanisms could each be given prominence and thus an estimate of the response of materials to different stimuli could be obtained. A target vehicle, which would confine an explosive and deliver a measured quantity of energy through an impact by a projectile, launched from a gas gun, has been designed, manufactured and used.

Experimental

Equipment

The gun used was 50 mm calibre firing in air against a mounted target NAG. Initially mechanical rupture of a diaphragm was used to fire the gun, but later gas pressurisation behind the sabot, through a venting valve was used as shown below.

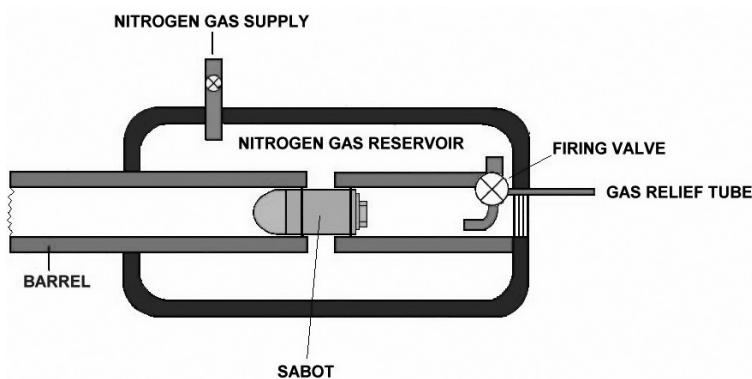


Figure 1. Schematic diagram of Gas gun arrangement with Sabot loaded.

This latter had the advantage of providing more sensitive pressure control. Three sabots were used (see Figure 2).



Figure 2. Typical sabots used in Tests.

The simple near spherical sabot was an attempt to reduce the effect of yawing of the projectile on impact energy and later the extended projectiles, with the widely spaced ‘O’ rings to obscure the venting orifices between the gas storage chamber and the barrel, were used. Both flat and round nosed projectiles had masses of 1.5 Kg. Lighter projectiles, 0.8 Kg, consisted of front and rear steel sections bolted together through a PVC tube which carried the obturation “O” rings as shown in the gun schematic. Sabot velocity was determined from the time taken break of a series of equally spaced wires stretched across a plastic tube through which the sabot passed after it had exited the barrel and before striking the target

Target Design

A range of targets assemblies was used. Initially simple and modified Steven test assemblies were used (see Figure 3).



Figure 3. Modified Steven test Assembly showing increased confinement.

Notice that the confining ring in the modified test was extended considerably over the cover plate leaving an uncovered area slightly larger than the sabot impact area and also down the sides of the body thus ensuring significant increase in confinement of the explosive over the original target design. More recent tests used an assembly shown below Figure 4.

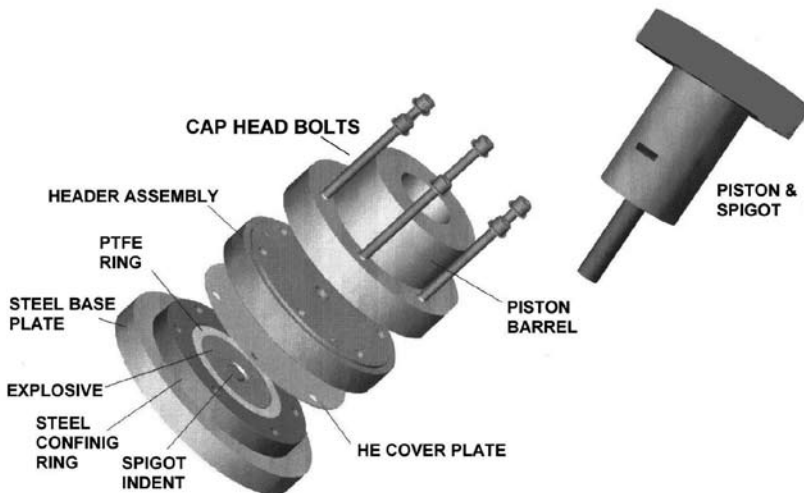


Figure 4. Schematic Target Assembly using moving piston mounted spigot in which a piston, with attached spigot, was driven into the explosive by impact of a gas gun launched sabot with the top of the piston.

Mounted within these assemblies were pellets of the explosive under test. Two pellet sizes were used, 70 mm and 25 mm diameter, by 15 mm thick Columns up to three pellets thick could be mounted in the target assembly and held in place by PTFE or PVC rings. Spigot penetration into the explosive was controlled by shims in front or behind the pellets, Figure 5.

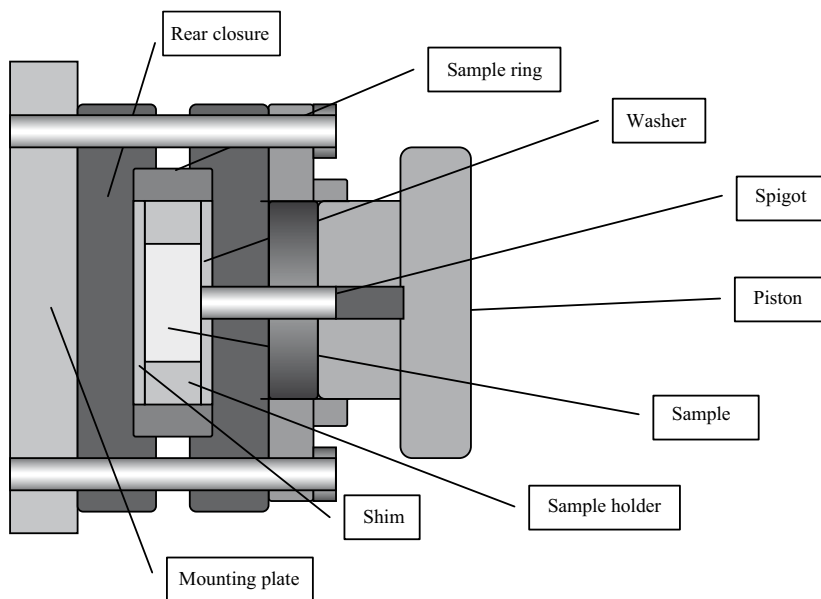


Figure 5. Target assembly (schematic).

This enabled the ignition mechanisms i.e. friction shear and nip sensitivities to be investigated. Some pellets had dimples machined into one face allowing air to be trapped between two pellets to investigating adiabatic heating effects.

In house manufactured PVDF pressure gauges were enclosed within the targets between pellets and also between pellets and housing surfaces. The intention was to monitor the pressure as the projectile struck and after reaction commenced. Experiments investigated the effect of spigot characteristics, diameter, shape and surface texture as well as penetration and nip on sensitivity. The range layout for the normal air gun NAG are shown in the Figure 6.

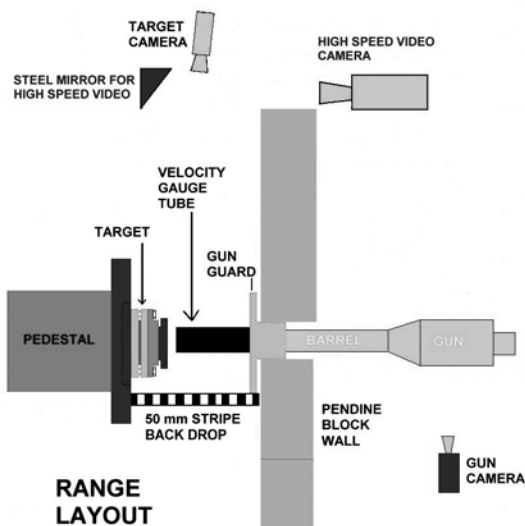


Figure 6. Schematic range layout for 50 mm NAG.

Events were monitored by high speed video camera and data recorded on fast recording oscilloscopes. All firings were performed remotely on the COTEC ranges on the edge of the Salisbury Plain Training Area at West Lavington.

Explosive compositions investigated were a PBX formulation based on HMX and PETN/WAX (92:8), both supplied by B.Ae. systems Glascoed, U.K. The PBX was hot, 363 K, pressed into 70 mm diameter 15 mm thick pellets at 100 MPa. The PETN/wax was pressed, at ambient temperatures without additional binder, into 25 mm diameter pellets 15 mm thick at 50 Mpa. The lower pressure was used for the PETN to reduce the risk of events even though the pressing was done remotely on the range facilities at the college. Some PETN pellets were pressed after removing the wax by solvent washing but these showed poor mechanical strength and so were not used beyond the preliminary stages.

Results and Discussion

(a) PBX

Some of the observed events occurring from the modified Steven tests were recorded at velocities $>100 \text{ m s}^{-1}$ by direct impact of the projectile. The induced reactions appeared to be deflagrations and metallographic examination

of the broken edges confirmed ductile failures. In the spigot impact tests the velocities of the spigot were less than the velocity of the impacting projectile but nevertheless events occurred at lower sabot speeds. This is an indication of the extent of the energy lost during the deformation of the steel cover of the Steven test. The results from a series of tests on the PBX composition with the spigot intrusion are shown in Table 1.

Table 1. Impact trial results PBX showing spigot configuration sabot velocity nature of event and mass of explosive recovered

Trial	Velocity m s ⁻¹	Event	Mass % Recovered
13 mm flat spigot	100	yes def.	42
13 mm flat spigot	65	no	92
13 mm diam. Flat Spigot air bubble	53	yes def.	48
As above	45	yes def.	45
As above	36	no smell	96
13 mm diam round nosed spigot	86	no sl. evi	95
	103	yes	52
4 mm round nose	115	no smell	97
Flat nosed	115	yes	30

When events occurred they were deflagrations; confirmed by metalographic examination of the fragments. In these PBX tests not all the explosive was consumed in the deflagration. As soon as the pressure generated exceeded the tensile strength of the bolts holding the target together the vehicle separated, the pressure released and the burning process was extinguished. About 50% of the contents were recovered from the floor of the test facility and the fragments of the target assembly. Even addition of a reinforcing plate over the piston housing, although it resulted in apparently more violent reaction, which distorted the covering plate, it was still a deflagration. The interesting point is that the smaller diameter piston seemed to require more energy to be deposited by the spigot since events only occurred at higher impact velocities. This is opposite to the effect predicted by Lee [8] based on energy density. The same energy over a smaller area should have an increased ignition effect. The reason for this may come from the motion of the spigot. Not all the energy imparted to the piston is delivered to the explosive. The piston is arrested by the carrier rather than the spigot in the explosive causing the stop. The explosive sample offers less resistance to the smaller spigot and hence the same energy may not be delivered for the same impact velocity. Methods for measuring the energy transferred to

the explosive by the spigot rather than just the piston K.E. are under evaluation. Simple conservation of momentum principles need modification.

Tests to confirm the effects of detonation were performed by mounting two explosive pellets which had been impacted but failed to initiate into a target assembly and inserting an electric detonator L2A1 in the cavity with the firing wires passing out through the gauge slots. The piston was inserted into the holder but was free to move. The whole assembly was mounted on the target plate in the normal mode and the detonator fired. Typical fragments are shown in the figure below.



Figure 7. Showing Rear Plate fragments recovered from full detonation in target.

The back plate was destroyed and the confining ring fragmented with the bottom plate perforated. The surprising effect was that the piston was retained in the carrier housing because the shock wave had mushroomed the end protruding beyond the carrier before the piston had chance to move backwards in the carrier. Notice how similar the fragments are to those obtained from the PETN samples mentioned below where the impact induced a run to detonation.

(b) PETN/wax

The results from these firings are summarised in the table below.

Table 2. PETN/wax results summary

Shot No.	Trial type	Spigot surface	Impact vel. Ms ⁻¹	Response
1	10 mm intrusion	plain	28.2	
2	10 mm intrusion	plain	47.77	event (old o rings)
3	10 mm intrusion	220 grit	41.8	spigot damaged
4	10 mm intrusion	plain	42.857	no reaction
5	10 mm intrusion	80 grit	42.25	event
6	10 mm intrusion	80 grit	37.1	confinement loss
7	15 mm Shear	plain	43.86	no reaction
8	15 mm Shear	plain	47.78	no reaction
9	Pinch	plain	47.32	event
10	Pinch	plain	84.74	event

The points of interest are that the spigots surface roughness appeared to influence the sensitivity. Shear was not found to be a particularly exciting stimulus in that none of our shear experiments produced an event even though we were firing at velocities at which both friction and pinch had given violent deflagrations. Pinch was deemed to be the most sensitive since reaction occurred at similar velocities to simple intrusion experiments but the event at the higher velocity of 87 m s⁻¹ was a detonation which did not occur with any of the other stimuli at that velocity. Examination of the target fragments recovered showed brittle fracture.

**Figure 8.** Firing 10 against PETN/wax showing target destruction.

The added wax is a desensitiser for the PETN but the sensitivity has not been reduced to the level of the PBX tested. Examination of the traces from the PVDF gauges show typical pressure increase leading to DDT following mechanical impact with increased velocity but below the shock threshold.

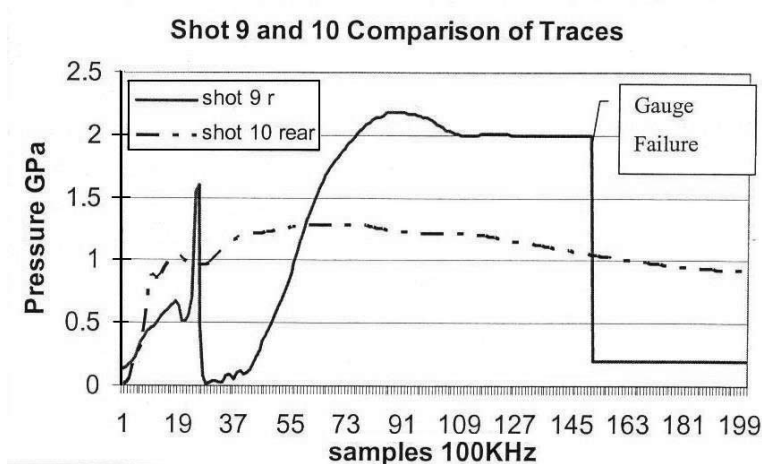


Figure 9. Showing Oscilloscope traces recorded from PVDF gauges mounted at front and rear of the target pellet.

Conclusions

The most significant stimuli for accidental initiation are:

- Pinch or nip of the explosive between end of spigot and rear steel plate.
- Gas compression within the explosive.
- Friction between explosive and spigot surface.
- Increasing surface roughness of spigot increases response to impact.
- Shape of the spigot is important. Flat fronted spigot impact results in events at lower velocities than hemispherical fronted spigots.
- Shear does not appear to be a significant source of initiation but may be a contributing factor.
- PETN when suitably confined can run to detonation before confinement is lost if the energy input is above the simple deflagration threshold.

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