UCRL-CONF-222305

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June 21, 2006

13th International Detonation Symposium
Norfolk, VA, United States
July 23, 2006 through July 28, 2006

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THRESHOLD STUDIES ON TNT, COMPOSITION B, C-4, AND ANFO EXPLOSIVES USING THE STEVEN IMPACT TEST

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Abstract. Steven Impact Tests were performed at low velocity on the explosives TNT (trinitrotolulene), Composition B (63% RDX, 36% TNT, and 1% wax by weight), C-4 (91% RDX, 5.3% Di (2-ethylhexyl) sebacate, 2.1% Polyisobutylene, and 1.6% motor oil by weight) and ANFO (94% ammonium Nitrate with 6% Fuel Oil) in attempts to obtain a threshold for reaction. A 76 mm helium driven gas gun was used to accelerate the Steven Test projectiles up to approximately 200 m/s in attempts to react (ignite) the explosive samples. Blast overpressure gauges, acoustic microphones, standard video and high-speed photography were used to characterize the level of any high explosive reaction violence. No bulk reactions were observed in the TNT, Composition B, C-4 or ANFO explosive samples impacted up to velocities in the range of 190-200 m/s. This work will outline the experimental details and discuss the lack of reaction when compared to the reaction thresholds of other common explosives. These results will also be compared to that of the Susan Test and reaction thresholds observed in the common small-scale safety tests such as the drop hammer and friction tests in hopes of drawing a correlation.

INTRODUCTION

The Steven Impact Test involves impacting a target with High Explosives (HE) at increasingly higher velocities with a projectile until you get a "GO" (reaction). A burning or deflagration process is generally observed in lieu of a full-scale detonation. The lowest velocity where you get a "GO" is considered the "reaction threshold" and typically involves several experiments to determine. Violence level data can be obtained from blast overpressure gauges and acoustic microphones placed near the experiment. Both the "reaction threshold" and violence level data can be utilized in various hydrodynamic reactive flow models to generate safety predictions for a variety of scenarios.

A number of Steven tests have been performed at the Lawrence Livermore National Laboratory[1-7] (LLNL) as well as modified versions of the test at Los Alamos National Laboratory[8-10] (LANL) and the Atomic Weapons Establishment (AWE) in the United Kingdon (UK). The use of overpressure gauges dates back to the Susan Test[11,12] and the overpressure transit data is used to calculate an equivalent point source energy[12] for samples that react.

The Steven Impact Test results to date have increased the fundamental knowledge and practical predictions of impact safety hazards for confined and unconfined explosive charges. However, up until this work, the Steven Impact test has mainly focused on Plastic Bonded Explosive (PBX) formulations. The tests described here expand the materials tested to commonly used (but not PBX) explosive samples TNT (trinitrotolulene), Composition B (63% RDX, 36% TNT, and 1% wax by weight), C-4 (91% RDX, 5.3% Di (2-ethylhexyl) sebacate, 2.1% Polyisobutylene, and 1.6% motor oil by weight) and ANFO (94% ammonium Nitrate with 6% Fuel Oil.

Generally, explosive safety test results on one material are compared on a relative scale with other materials used in the same test. An eventual goal would be to correlate the results from a variety of small-scale safety tests[11] together to increase the predictive capability and also add value to each test.

The results of the Steven Impact Tests will be contrasted with that of the Susan Impact Test[11,12] since this is a historic test that is no longer performed, as well as typical drop hammer and friction test results[11]. In comparing these results, there will likely be a difference due to the sample size differences and the relative amounts of friction, shear, and strain the sample observes.

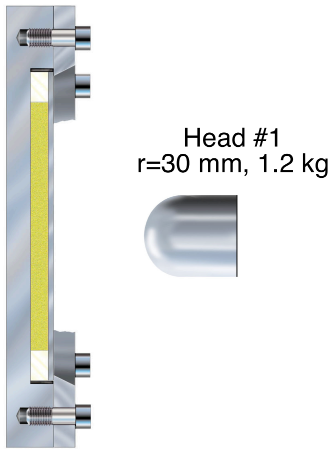

FIGURE 1. Schematic diagram of the Steven Impact Test arrangement with the projectile head used in this work.

EXPERIMENTAL PROCEDURE

The experimental geometry of the Steven Impact Test target and details of the projectile used are shown in Fig. 1. The projectile head consists of a steel cylinder with a 30.05 mm radius hemispherical impact surface and mass of 1.2 kg. A gas gun accelerates the steel projectile head attached to an aluminum sabot into a 110 mm diameter by 12.85 mm thick explosive charge confined by a 3.18 mm thick steel plate on the impact face, a 19.05 mm thick steel plate on the rear surface, and 26.7 mm thick steel side confinement. A Teflon ring around the explosive provides radial confinement.

For these experiments, a 76 mm diameter smooth bore gas gun located at LLNL Site 300, bunker 850 was utilized and fires onto an outdoor firing table. The steel projectile head (see Fig. 1) is attached to an aluminum sabot body that is accelerated via compressed helium gas into the target. External blast overpressure gauges were placed around the target at a 3.05 m standoff for direct comparison to the Susan test data [11]. Acoustic microphones, standard video, and high speed digital photography were also used to characterize the event.

Test target pucks were cast from TNT (trinitrotolulene) and Composition B (63% RDX, 36% TNT, and 1% wax by weight) to be assembled into the target fixture. In the case of the putty like explosive C-4 (91% RDX, 5.3% Di (2-ethylhexyl) sebacate, 2.1% Polyisobutylene, and 1.6% motor oil by weight), the material was hand packed into the test target cavity. ANFO prills were poured into the target cavity to tap density. Figure 2 displays photographs of a typical Steven Test target before and after loading of the explosive sample. In all targets, APC 2.5 potting compound was used for the solid pucks, the target puck was placed in while the potting compound was still wet, for the paste and pour explosives, the potting compound was fully cured before adding the paste or granular material. Figure 3 displays photographs of the individual materials as loaded into the target before the cover plate is put in place.

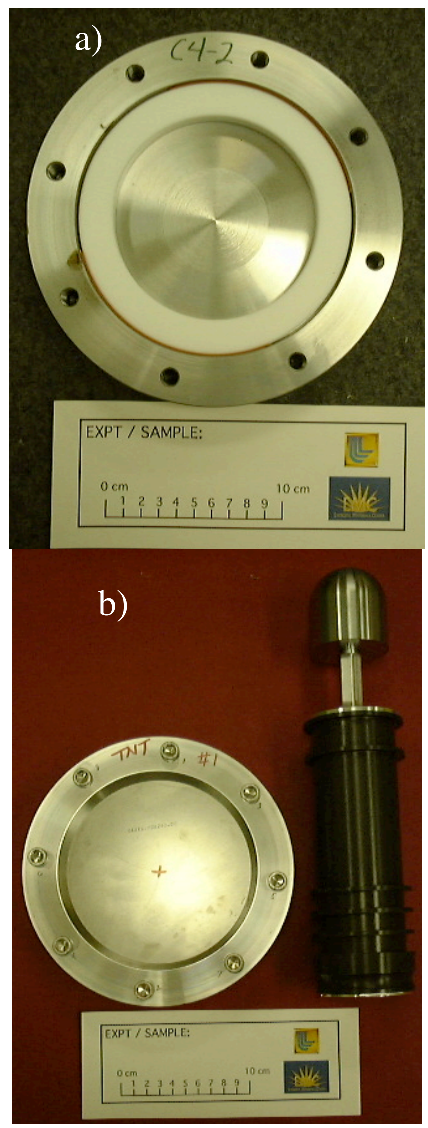

FIGURE 2. Photographs showing (a) the Steven Test target before loading and (b) after assembly with a projectile assembly.

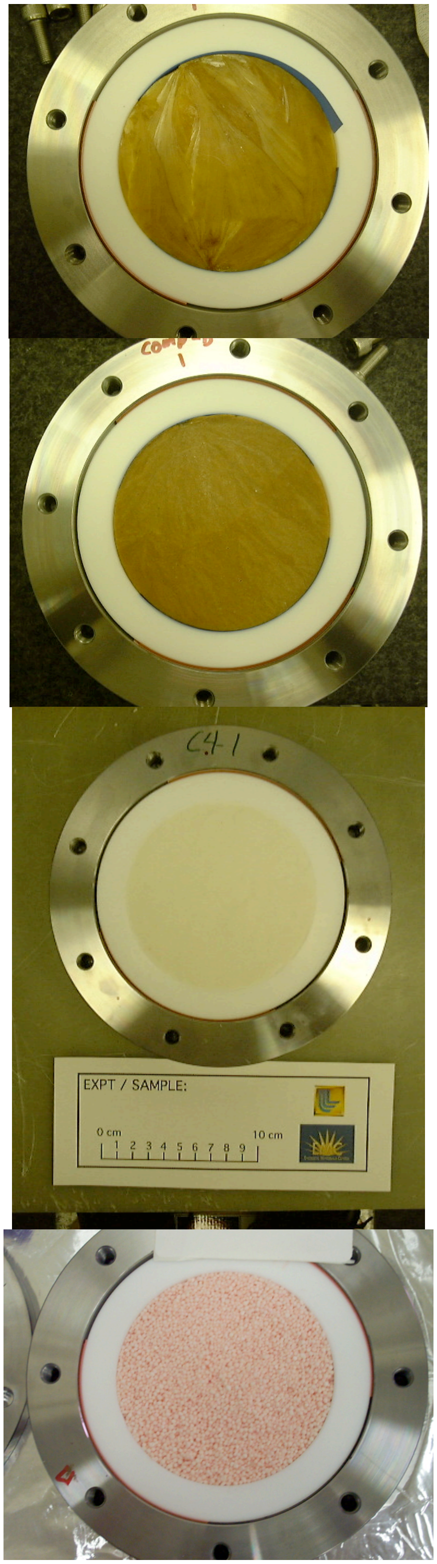

FIGURE 3. Photographs showing the loaded Steven Test samples before the cover plate is placed on the target for (a) TNT, (b) Comp B (c) C-4, and (d) ANFO prill.

RESULTS/DISCUSSION

The tabulated results for this work are included in Table I. The description includes the shot number, material, velocity of impact, whether the test was a "GO" or a "NOGO," and any notes that might be relevant to the particular test. Note that some of the targets were hit more than once as indicated in the last two digits of the shot number (.01 is first hit, .02 is second hit, and so on) as well as in the notes column of whether the target was in tact and able to be hit again.

As seen in Table I, all of the experiments were "NOGO's" indicating no bulk reactions in the materials up to the range of 190-200 m/s. Because friction and shear are known mechanisms for reaction in the Steven Test, these results suggest that the friction may be minimized in the impact event. In the case of C-4, it is a putty like explosive that contains a small amount of motor oil so it is not hard to believe that the material is allowed to flow rather easily upon impact. A small fireball was seen in the highest velocity experiment (195 m/s), but this could be a small amount of barrel lubricant igniting due to friction with the front cover of even a very small amount of material becoming pinched between the deformed cover and the back of the target. This amount of reaction was not significant.

TABLE 1. Test results for Steven Test experiments.

Expt #	Material	Velocity (m/s)	GO / NOGO?
001.01	TNT	75 m/s	NOGO
001.02	TNT	87 m/s	NOGO
002.01	TNT	98 m/s	NOGO
002.02	TNT	108 m/s	NOGO
003.01	TNT	108 m/s	NOGO
003.02	TNT	116 m/s	NOGO
004.01	TNT	155 m/s	NOGO
004.02	TNT	182 m/s	NOGO
005.01	TNT	189 m/s	NOGO
006.01	Comp B	66 m/s	NOGO
006.02	Comp B	87 m/s	NOGO
006.03	Comp B	116 m/s	NOGO
007.01	Comp B	153 m/s	NOGO
008.01	Comp B	198 m/s	NOGO
011.01	C-4	157 m/s	NOGO
011.02	C-4	183 m/s	NOGO
012.01	C-4	190 m/s	NOGO
012.02	C-4	195 m/s	NOGO
017.01	ANFO	~154 m/s	NOGO
017.02	ANFO	~182 m/s	NOGO
018.01	ANFO	~195 m/s	NOGO
018.02	ANFO	~197 m/s	NOGO

For the TNT and composition B materials that are solid in nature, the flow of material does not appear to be the obvious case. However, TNT has a relatively low melting point of 80°C, which might be melting under the friction of impact and allowing the material to flow. This would explain the result for both TNT and Composition B (containing 36% TNT), but without any further investigation this is just a simple guess. The relatively large crystal size (see Figure 3) of the TNT and Composition B material may also be a contributing factor to the high threshold, even if melting of the TNT is not a dominating factor. For the ANFO prill material, the presence of 6% diesel fuel that is oily in nature probably acts to allow the material to flow similar to C-4 as the round prills break up upon impact.

COMPARISON TO OTHER TESTS

Figure 4 displays a bar chart comparing the reaction thresholds for the Steven Impact test, Susan Impact test, Drop Hammer test, and the Friction test. The samples from this work are included as well as some common PBX explosives for comparison purposes. Note that for TNT, Composition B, C-4, and ANFO samples, the Steven Test threshold extend to the far right. The TNT, C-4, an ANFO have relatively high drop hammer results that might be a good indicator for the high Steven Test threshold. The Friction values for C-4, TNT and Composition B3 (a slightly modified version of Composition B), are relatively low though indicating that the friction effect might not be the dominant mechanism for these materials.

Realize that this comparison may not be completely valid due to the sample size differences. In the drop hammer and friction tests, the samples sizes are relatively small milligram quantities, while the Steven and Susan samples are in the range of hundreds of grams. And a clear trend is not observed when comparing the small-scale results to the Steven Test, but a general comparison in this direction might be a start toward a better understanding.

Comparing the Steven Test results to the Susan Test does not reveal a significant trend for these materials. The Susan Test geometry is shown in Figure 5. Although there are not any Susan Test results for ANFO and C-4, the TNT and Composition B have Susan Test thresholds way below the threshold for that of the Steven Test. These differences probably have to do with the sample geometry and deformation characteristics. These characteristics are discussed further in the following section.

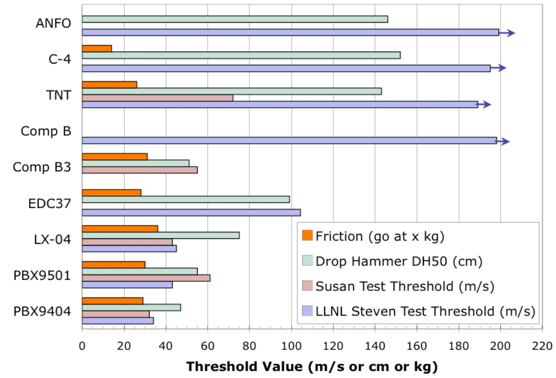

FIGURE 4. Bar chart comparing the Steven Test Threshold, Susan Test threshold, Drop Hammer small-scale test, and Friction small-scale test results. Some common PBX explosives are also included for comparison.

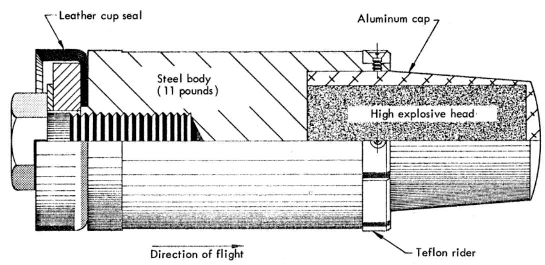

FIGURE 5. Schematic of the Susan Impact Test (taken from Reference 12). The explosive sample is 50.8 mm diameter and 101.6 mm long.

STEVEN TEST AND SUSAN TEST SAMPLE DEFORMATION CHARACTERISTICS

In the case of Composition B and TNT, the threshold in the Susan Test is low compared to that in the Steven Test whereas the PBX samples are grouped pretty closely together. This is likely due to the sample deformation characteristic differences in these two tests. The aspect ratios of the samples are different with the Steven Test sample (110 mm diameter by 12.85 mm thick) taking the shape a relatively large diameter thin puck when compared to the Susan Test sample that resembles a circular cylinder (50.8 mm diameter by 101.6 mm long).

Figure 6 shows photographs from a TNT target that has been impacted (a) once and (b) two times. The impact is generally slightly off center, and the target is rotated and impacted again at an opposing off-center location. Compare this to the schematic depictions of the early stages of deformation and the Pinch stages in the Susan Impact test shown in

Figure 7. In the Steven Test, the thin puck design allows it to be hit multiple times before the cover comes apart or splits. The Susan Test explosive sample makes up a projectile, so firing it a second time would probably not be advised. As shown in Figure 7, the two main stages of deformation consist of an early stage followed by a later (or "pinch") stage. Because the Steven Test target geometry is such that it will only allow a similar scenario as the early deformation stage of the Susan Test, if the samples react in the "pinch" stage in the Susan Test, it may not necessarily be observed in the Steven Test. This appears to be the case with the TNT and Compositoin B samples. Because Susan Tests were not performed on C-4 or ANFO, the comparison cannot be made. However, outlining these difference is an important factor in potential future comparisons of the Steven Test to the Susan Test.

FIGURE 6. Photographs from a TNT target impacted (a) once and (b) after two impacts.

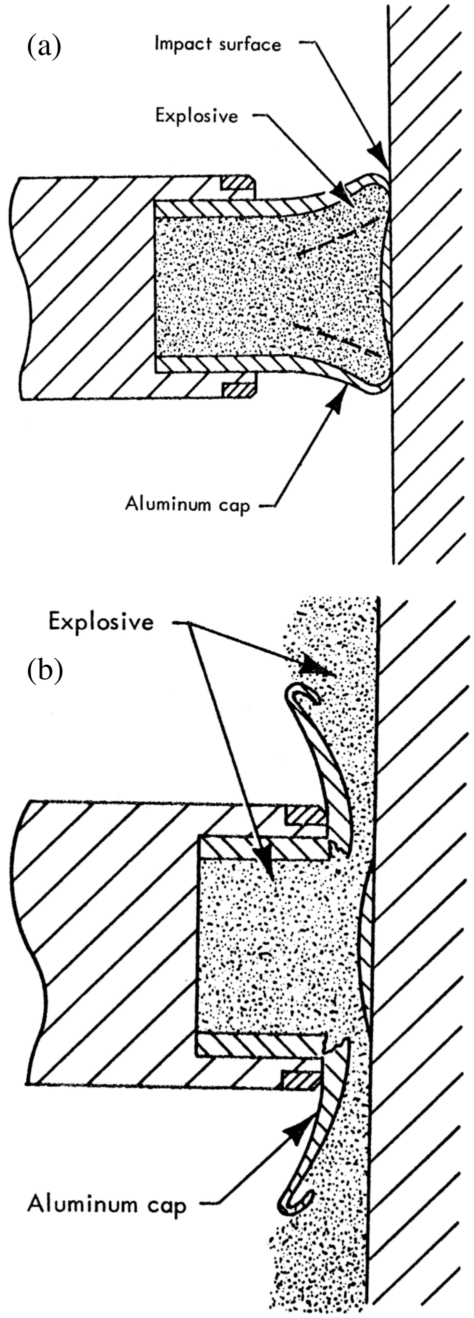

FIGURE 7. Schematic depictions of the early stages of deformation and (b) the Pinch stage in the Susan Impact test taken from Reference 12.

SUMMARY AND FUTURE WORK

Steven Impact Tests were performed at low velocity using a 76 mm helium driven gas gun on the explosive samples TNT, Comp B, C-4 and ANFO to obtain a threshold for reaction. No bulk reactions were observed in any of the explosive samples impacted up to velocities in the range of 190-200 m/s. These results display that these materials are relatively safe in impact type scenarios. In comparing these Steven Test results to that of small-scale safety drop hammer and friction test data, a clear correlation is not evident. And the sample geometry differences in the Steven Test and Susan Test make the comparison not as strong where large deformations might be observed.

ACKNOWLEDGEMENTS

The 76 mm gun crew at Site 300 (Bunker 850) is thanked (especially main crew) for their hard work. Funding for this research provided through the Nuclear Counterterrorism Design Support (NCDS) Program at LLNL and is greatly appreciated. This work was performed under the auspices of the U. S. Department of Energy by the University of California, Lawrence Livermore National Laboratory under Contract No. W-7405-Eng-48.

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