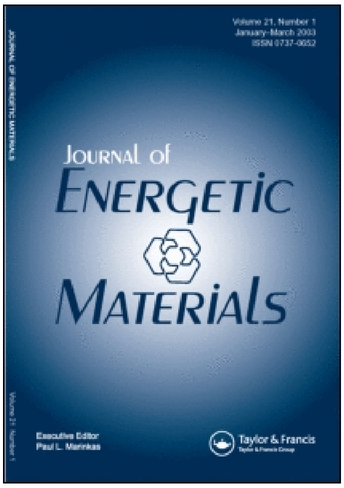

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J. Waschl[a]; D. Richardson[a]
[a] DSTO Materials Research Laboratory, Australia

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EFFECT OF SPECIFIC SURFACE AREA ON THE SENSITIVITY OF HEXANITROSTILBENE TO FLYER PLATE IMPACT

J. Waschl and D. Richardson

DSTO Materials Research Laboratory
PO Box 50, Ascot Vale, Vic 3032
Australia

ABSTRACT

The sensitivity of hexanitrostilbene (HNS) to flyer plate impact over a wide range of Specific Surface Area (SSA) has been investigated. Maximum sensitivity was found to occur at SSA between 10 and 20 m^2/g for HNS pressed to 90% theoretical maximum density (TMD). Above and below this SSA the sensitivity was found to decrease. The sensitivity was also found to decrease as the density increased for HNS with an SSA of 10.3 m^2/g. The hot spot and grain burning theories are employed to explain these phenomena and to relate pulse duration to the sensitivity of HNS. At high SSA, it was observed that the HNS exhibited 'low order' response to shock impact.

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INTRODUCTION

There have been several studies on the shock sensitivity of pressed hexanitrostilbene (HNS) explosive[1,2,3]. In general the sensitivity has been found to depend on the Specific Surface Area (SSA) of the HNS and on the pressure and duration of the incident shock[1,2,3].

Setchell[1] measured the chemical reactivity for two types of HNS samples under both sustained and short duration shocks (∿ 400 ns). One HNS sample had an SSA of 2.1 m^2/g, the other an SSA of 8.2 m^2/g. In his study, Setchell also recorded the intensity of the visible emission spectra and particle velocities at the rear surface of the explosive following a planar shock impact. It was discovered that the lower SSA sample exhibited chemical reaction at lower impact pressures for both sustained and short duration shocks. Setchell had previously reported[2] that low SSA HNS was more sensitive than high SSA HNS for shock durations as short as 190 ns. Setchell[1] proposed that for the case of short duration shocks the high and low SSA HNS have fundamentally different initiation behaviours.

Schwarz[3], on the other hand, employed thin flyer plates to produce very short duration pulses (< 40 ns) against three types of HNS; SSA of 1.6 m^2/g, 2.6 m^2/g and approximately 10 m^2/g. It was found that the sample with SSA of 10 m^2/g initiated at the lowest pressure and also exhibited a shorter run to detonation distance.

Hayes[4] predicted the same sensitivity trend for a similar range of SSA of HNS. Another granular explosive, TATB, investigated over a smaller range of SSA by Honodel et al[5] indicated that fine TATB was more sensitive than coarse TATB for thin flyer plate impact. Price[6] summarized these results by suggesting that there is a pressure above which the fine material appears more sensitive than the coarse.

The concepts of hot spot formation[7,8] and grain burning[9] have been developed in order to understand the shock initiation and subsequent detonation of pressed granular explosives. Recent models of the shock sensitivity of heterogeneous explosives have incorporated these concepts[10,11]. Tarver et al[10] employed a phenomenological ignition and growth model for the short duration shock initiation of heterogeneous solid explosives (e.g. PBX 9404). This model consisted of three stages: a) the formation of hot spots; b) a relatively slow growth of reaction by inward or outward burning at these hot spots and c) a rapid completion of the reaction as the hot spots combined. The model provided good agreement with experimental results for the shock initiation of PBX 9404 by thin flyer plates. It did not, however, consider the effect of changes in SSA of the explosive.

Kipp and Setchell[11] have developed a model for fine-grained or high SSA HNS. This model assumes that as the SSA of the HNS increases, the explosive exhibits homogeneous characteristics, namely the formation of a superdetonation wave. Employing this assumption, a two phase equation of state was developed to model high SSA HNS. This model employed Arrhenius kinetics in a two step process. The model showed good agreement with experimental data for the shock initiation of HNS. Two features of this model are the predictions of the formation of a superdetonation wave and the formation of unsteady detonation as threshold conditions are approached.

The concept of a high SSA heterogeneous explosive displaying shock sensitivity behaviour normally attributed to a homogeneous explosive is presently at issue. We have addressed this problem by investigating the shock sensitivity of granular HNS to extremely short duration pulses. This is similar to the work of Schwarz[3], although a much wider range of SSA has been considered. The purpose of this investigation was to determine the change in the sensitivity of HNS to very short duration shocks as the SSA increased.

EXPERIMENTAL

A small version of the electric gun[12] was employed to propel a thin flyer plate at the explosive. The Kapton flyer plates used were approximately 25 μm thick and the copper metal bridges approximately 4 μm thick. The acceptor explosive pellet was HNS pressed to either 85%, 90% or 95% theoretical maximum density (TMD). Each explosive pellet was of diameter 4 mm and had a nominal mass of 50 mg. The range of SSA investigated was between 3 and

42 m^2/g. All samples had residual dimethylformamide (DMF) of less than 0.9%. The high SSA explosive was prepared by crash precipitation under special conditions[13]. SSA was measured on a Micromeritics Flowsorb 11 2300 Surface Analyser.

The sensitivity of the HNS was assessed on the basis of the firing energy required. High energies equate to high impact velocities and therefore high impact pressures. The firing energy was adjusted in an 'up-down' Bruceton[14] approach to determine the point at which 50% ($E_{50\%}$) of the pellets were initiated. Approximately twenty pellets were used to determine each $E_{50\%}$.

The current through the metal bridge and the voltage across the bridge were monitored during all firings. In addition, a piezoelectric gauge was employed to detect impact of either the flyer plate or the detonation wave from the acceptor pellet.

By employing the above gauge the excess transit time of the detonation wave through the pellet could also be calculated. Due to size constraints, an indirect method was employed to determine the excess transit times. Our method was divided into two parts.

The first part consisted of measuring the transit time of the flyer (t_f) through the barrel. This was achieved by impacting the flyer onto a piezoelectric detector in place of the acceptor explosive. Time zero was taken as the peak in the voltage trace which corresponds to the burst time of the bridge and therefore to the initial motion of the flyer plate. Measurements were taken at several firing energies.

The second part consisted of placing the piezoelectric gauge on the rear surface of the acceptor explosive and measuring the transit time of the flyer and detonation wave (t_T) from the same reference point. The excess transit time (t) is then given by:

$$t = x_1/v_d - (t_T - t_f) \qquad (1)$$

where x_1 is the pellet length (typically 2 to 3 mm) and v_d is the steady state detonation velocity (6.9 mm/μs[3]).

The effect of density changes on $E_{50\%}$ were also investigated. This was done for HNS with an SSA of 10.3 m^2/g pressed to 85%, 90% and 95% TMD.

RESULTS

Impact velocities could not be measured; therefore only estimates of the shock pressure and duration could be made. Based on initiation energies reported in the literature[3,11] however, flyer velocities were estimated to be at least 2.5 mm/μs at threshold. Shock durations for these experiments were therefore calculated to be no more than 20 ns.

As the absolute energy levels cannot be presented, all energy data is provided in relative terms. A plot of the relative energy of initiation of HNS samples pressed to 90% TMD as a function of SSA is shown in Figure 1. The data suggest that a minimum initiation energy exists for an SSA between 10 and 20 m^2/g.

As the SSA was increased it became more difficult to determine whether detonation had occurred. For low SSA HNS the distinction was clear cut; a detonation pulverised the surrounding pellet holder, otherwise the pellet and holder remained intact, with a small hole or crater often being observed on the impacted surface of the explosive. For the high SSA HNS the damage to the surrounding pellet holder was typically reduced. On a number of occasions the holder was recovered intact even though the explosive pellet appeared to have partially reacted. In one instance no explosive remained at all.

One way of investigating the reaction mechanisms is to quantify the time domain of the event. For this reason it was decided to measure the excess transit time.

The measured transit times of the flyer plates were measured between 80 and 180 ns. The results are shown in Figure 2. The data was fitted by the Levenberg-Marquardt method[15] to the following equation:

$$t_f = 173\, e^{-0.004(V-972)} + 73 \qquad (2)$$

where t_f is the flight time in nanoseconds and V is the firing voltage in volts.

For a range of SSA samples, excess transit times (t) were calculated using equations 1 and

2 with t_T values ranging from 400 to 700 ns. The results are shown in Table 1. The quoted values are averages of several shots. The measured t values do not include the two instances near $E_{50\%}$ where although a signal was detected the pellet holder was later found to be intact. In these cases the t values were much longer and the calculated average shock velocities through the pellets were found to be 1.4 and 4.4 mm/μs.

TABLE 1

Excess Transit Times (t) and SSA for Various Samples of HNS Flyer Plate Impact

SSA m^2/g	t ns
3	28 ± 7
10.3	11 ± 19
32	32 ± 4
42	32 ± 23

Table 2 shows the change in relative energy for initiation of HNS with SSA 10.3 m^2/g as the density is increased. All results are related to the $E_{50\%}$ point at which a 90% TMD sample of 10.3 m^2/g HNS sample initiated.

TABLE 2

Effect of Density Changes on the Sensitivity of HNS at an SSA of 10.3 m^2/g

Density %TMD	Relative Energy $E_{50\%}/E_{50\%}$ at 90% TMD
85	0.80
90	1
95	1.09

DISCUSSION

A granular heterogeneous explosive such as HNS contains density inhomogeneities or voids which increase in size and number as the %TMD decreases. In low SSA granular explosives pressed to ≥ 90% TMD, there is only a small number of relatively large voids. These voids provide potential sites of high temperature under shock impact conditions[4,16,17]. In higher SSA granular explosives at the same density the individual void volume decreases and the void numbers increase. The reduced size of these voids implies that a reduced volume of explosive may be ignited under the same impact conditions. Schwarz[3] has demonstrated that for very short duration shocks (< 40 ns), rapid attenuation of the transmitted shock ensures that only a small volume near the surface of the granular explosive experiences the peak pressure. For any SSA, increasing the pressure at impact increases both the temperature of the hot spots[4] and possibly the number of hot spots formed.

If hot spot formation were the only important consideration, low SSA materials would therefore be easier to detonate under very short shock impacts. Figure 1 and the results of Schwarz[3], however, suggest that a further mechanism is important. This mechanism is grain burning and, as shown by Hayes[4], Howe et al[9] and by Hayes and Mitchell[18], the grain burning rate is directly proportional to the SSA of the explosive; i.e. faster reaction rates occur as the SSA increases.

It is apparent from the sensitivity results shown in Fig. 1 that the competing mechanisms governing hot spot formation and grain burning rates combine to produce a minimum initiation energy region for very short duration pulses. For HNS at 90% TMD this region corresponds to an SSA between 10 and 20 m^2/g. Within this domain the shock sensitivity of the HNS is independent, within experimental error, of the SSA.

Mader and Kershner[16] predicted that such a minimum could occur as the hot spot size reduced and the number of sites increased, although no experimental evidence was provided. Kipp and Setchell[11] have implied a similar effect based on the prediction that as the SSA increases, the explosive is likely to react in a more homogeneous manner.

For SSA < 10 m^2/g, ignition may occur, but unless build-up is fast enough to allow the liberated energy to be coupled to the shock wave before the advancing rarefaction quenches the reaction, detonation may not proceed. Higher impact pressures are therefore required to increase the temperature[6] and number of potential ignition sites. This assists in the build-up phase although at the expense of an increased initiation energy as shown in Fig. 1.

As the SSA is increased above 20 m^2/g, the size of the voids decreases and the explosive media approaches a 'pseudo-homogeneous' state. Although the bulk material is still heterogeneous, the discontinuities become extremely fine and the distinction between heterogeneous and homogeneous is less clear. The small voids still provide sites for hot spot formation, although hot spot temperatures may be lower[5,8,16]; ignition may therefore not occur. Raising the impact pressure increases both the number and temperature of the hot spots formed and enables successful ignition. For fixed flyer plate dimensions, however, increasing the pressure reduces the shock duration. Therefore, build-up to detonation becomes critical and is only possible if the burning rate of the explosive grains is fast enough.

Thus, for extremely short duration shocks (20 ns in this study), the data presented here suggests that the rate at which chemical reaction occurs is critical; i.e. after ignition has occurred the build-up phase may still fail and detonation may be prevented. For very high SSA HNS, much higher pressures with correspondingly shorter duration pulses provided by the thin flyer plates are required to ignite the explosive as shown in Fig. 1 for SSA > 20 m^2/g. Once the explosive is ignited it is the burning rate that becomes crucial. It is only because the burning rate increases as the SSA increases that the build-up phase may be successfully completed with such short duration shock pulses. The delicate balance between the fast burning rate achieveable and the high impact pressure required, however, may eventually be broken as the SSA increases further. It is suggested that ultimately it is the build-up phase which prevents successful detonation from occurring in this regime.

If the initial pressure is high enough to ignite the explosive, then, provided the build-up phase is shorter than the shock duration, detonation will ensue. It appears that for very high SSA explosives (those approaching homogeneity) the high impact pressures required to ignite the explosive inhibit successful completion of the build-up phase since the shock duration is much shorter than the time to establish a self-sustaining reaction. Under these conditions, a partial reaction or unsteady build-up may occur as modelled by Kipp and Setchell[11]. Experimental evidence for this is found in the so called 'low order' events observed and in the two instances near $E_{50\%}$ where low average shock velocities were calculated. These calculated velocities provide particularly strong evidence for a subdued reaction occuring as the original shock is attenuated well before reaching the opposite face of the HNS target. A direct consequence of this nexus between shock duration and burning rates is that there is expected to be an upper limit of SSA for which shock initiation of HNS by a thin flyer plate of fixed dimension cannot proceed. This may be characteristic of all heterogeneous explosives.

The excess times recorded in Table 1 were based on small samples. The technique provided consistent results considering the short times measured. The results indicate that the excess times are small and that growth to detonation is rapid for all SSA investigated. There is possibly a minimum transit time for SSA of 10.3 m^2/g or maybe even an SSA effect on v_d, but further tests will need to be carried out to confirm these notions.

The increased sensitivity of the HNS as the density was decreased is in agreement with the results of Schwarz[3] and Roth[19]. As the %TMD decreases both the void volume and number density increase for a given SSA. Under shock impact the large hot spots formed will decompose a large amount of explosive. This effect combined with the greater number of hot spots formed, ensures that the relative energy for initiation decreases as indicated in Table 2. Although the investigation of the density effect for higher SSA HNS has not yet been completed, the described trend is expected to continue. Very high SSA HNS has a very low bulk density and difficulties in pressing this material will limit the extent of this investigation.

CONCLUSIONS

Results of this study indicate that for very short duration impacts (< 20 ns) there is an optimum range of SSA for HNS pressed to 90% TMD, where the energy for initiation is a minimum. This optimum region occurred for an SSA between about 10 and 20 m^2/g. Other granular explosives are expected to exhibit similar behaviour.

The measured excess transit times generally indicated that the initiation of HNS is prompt over a wide range of SSA. As the SSA is increased beyond 20 m^2/g, however, the HNS seems to exhibit an unsteady build-up that may not lead to detonation. A long excess time may also become apparent. This 'low order' event is probably related to only partial reaction occuring. These observations are probably also indicative of the changing relative importance of the competing initiation mechanisms occuring within the HNS explosive as the pore size and distribution changes. These results can be interpreted in terms of HNS, considered as a heterogeneous explosive, displaying pseudo-homogeneous behaviour as the SSA increases.

The increase in sensitivity of the HNS as the density decreases is explained by the greater porosity and larger average size of the pores. It remains to be determined where the maximum sensitivity of HNS occurs as a function of both SSA and density.

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REFERENCES

1. R.E. Setchell, Experimental Studies of Chemical Reactivity during Shock Initiation of Hexanitrostilbene, Proceedings of the Eighth Symposium (International) on Detonation, Naval Surface Weapons Center, **15** (1985).

2. R.E. Setchell, Grain-Size Effects on the Shock Sensitivity of Hexanitrostilbene (HNS) Explosive, Combustion and Flame, **56**, 343 (1984).

3. A.C. Schwarz, Study of Factors which Influence the Shock-Initiation Sensitivity of Hexanitrostilbene (HNS), SAND80-2372, 1981.

4. D.B. Hayes, Shock Induced Hot-Spot Formation and Subsequent Decomposition in Granular, Porous HNS Explosive, in Prog. Astro. Aero., **87**, 445 (1983).

5. C.A. Honodel, J.R. Humphrey, R.C. Weingart, R.S. Lee and P. Kramer, Shock initiation of TATB Formulations. Proceedings of the Seventh Symposium (International) on Detonation, Naval Surface Weapons Center, 425 (1982).

6. D. Price, Effect of Particle Size on the Shock Sensitivity of Porous HE, JOEM, **6**, 283 (1988).

7. C.L. Mader, Numerical Modeling of Detonation. Uni. of California Press, Berkeley, 1979.

8. R.E. Setchell and P.A. Taylor, The Effects of Grain Size on Shock Initiation Mechanisims in Hexanitrostilbene (HNS) Explosive. 9th ICODERS Poitiers, France, 350 (1984).

9. P. Howe, R. Frey, B. Taylor and V. Boyle, Shock Initiation and the Critical Energy Concept, Proceedings of the Sixth Symposium (International) on Detonation, Naval Surface Weapons Center, **11** (1976).

10. C.M. Tarver, J.O. Hallquist and L.M. Erikson, Modeling Short Pulse Duration Shock Initiation of Solid Explosives. Proceedings of the Eighth Symposium (International) on Detonation, Naval Surface Weapons Center, 951 (1985).

11. M.E. Kipp and R.E. Setchell, A Shock Initiation Model for Fine-Grained Hexanitrostilbene, Preprints Proceeding of the Ninth Symposium (International) on Detonation, Naval Surface Weapons Center, preprints 103 (1989).

12. R.C. Weingart, R.S. Lee, R.K. Jackson and N.L. Parker, Acceleration of Thin Flyers by Exploding Metal Foils: Application to Initiation Studies. Proceedings of the Sixth Symposium (International) on Detonation, Naval Surface Weapons Center, 653 (1976).

13. L. Montelli and R. Spear, MRL (1990) Commercial-in-Confidence.

14. W.J. Dixon and A.M. Mood, A Method for Obtaining and Analysing Sensitivity Data, J. American Statistical Ass., **43**, 109 (1948).

15. W.H. Press, B.P. Flannery, S.A. Teukolsky and W.T. Vetterling, Numerical Recipes: The Art of Scientific Computing. Cambridge Uni Press, Cambridge, 1987.

16. C.L. Mader and J.D. Kershner, The Three-Dimensional Hydrodynamic Hot-Spot Model. Proceedings of the Eighth Symposium (International) on Detonation, Naval Surface Weapons Center, **42** (1985).

17. P.A. Taylor, The Effects of Material Microstructure on the Shock Sensitivity of Porous Granular Explosive. Proceedings of the Eighth Symposium (International) on Detonation, Naval Surface Weapons Center, **26** (1985).

18. D.B. Hayes and N.M. Mitchell, A Constitutive Equation for the Shock Reponse of Porous Hexanitrostilbene (HNS) Explosive, SAND 78-0035, 1978.

19. J. Roth, Shock Sensitivity and Hugoniots of High Density Granular Explosives. Proceedings of the Fifth Symposium (International) on Detonation, Naval Surface Weapons Center, 219 (1972).

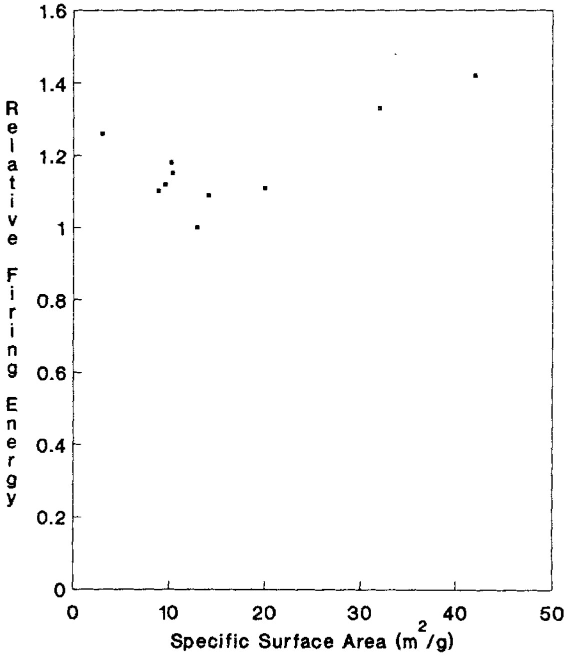

FIGURE 1 The relationship between relative firing energy and specific surface area for HNS pressed to 90% TMD and initiated by flyer plate impact.

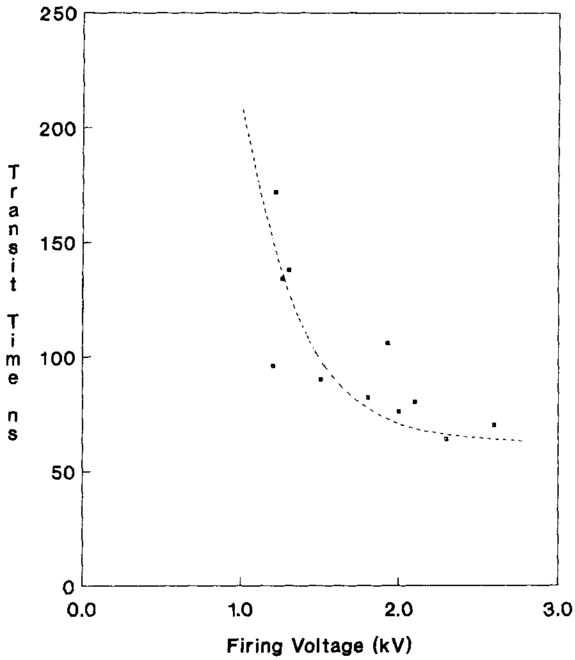

FIGURE 2 The relationship between transit time and firing voltage for small flyer plates.