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A STUDY OF BLAST CHARACTERISTICS OF SEVERAL PRIMARY EXPLOSIVES AND PYROTECHNIC COMPOSITIONS

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Summary

The blast characteristics of small quantities of a range of primary explosives and pyrotechnic compositions have been measured. The results show good agreement with standard scaled distance predictive equations developed for use with secondary explosives. In the configuration examined the blast characteristics and TNT equivalence values are of the same order of magnitude as TNT and there is no definite separation between the hazards associated with primary explosives and pyrotechnics. However, the TNT equivalence values may be significantly dependent on the mass of material, the distance from the blast and the experimental arrangement.

Introduction

Knowledge of the blast effects produced by an energetic material is important not only in calculating the quantities of the material required to achieve a desired, disruptive effect, but also in determining the level of safety of personnel handling the material and possibly exposed to a blast wave.

In the past, evaluation of the blast effects of energetic materials has been based on information from either published pressure/time data and predictive equations [1–3] or via surveys of military and civilian personnel exposed to blast waves [4–6]. In almost all cases, the energetic materials evaluated are secondary explosives and involve large quantities of material (>1 kg). Some information is available on primary explosives and pyrotechnic compositions, but again large quantities are involved and the range of materials is limited [7–11].

In the following, the blast characteristics of small quantities of selected primary explosives and pyrotechnic compositions are measured and compared to TNT. In addition the use of existing (secondary explosive) predictive equations and "TNT equivalence" is examined.

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Experimental

Details of the materials examined are given in Table 1. The range of materials covers primary explosives, primary explosives mixed with inert chemicals, and pyrotechnic compositions. The materials were loose-filled into mild steel test units (4.6 cm×2.5 cm×2.5 cm; 0.9 cm hole diameter) and sealed with a cork disc and adhesive (Fig. 1). The mass of material was limited to between 200 mg and 1000 mg and was initiated with either an ICI Type "E" fusehead containing approximately 30 mg of a potassium chlorate/charcoal/lead mononitroresorcinate mixture or with a delay composition comprising $B/Si/KNO_3$ (20:10:70).

Pressure–time measurements were made with a Bruel and Kjaer Model 4138 microphone connected to a Bruel and Kjaer Model 2209 impulse precision sound level meter. The pressure–time signals were recorded by connecting a digital oscilloscope to the sound level meter signal output. Hard copy records were obtained with a strip chart recorder connected to the cathode ray oscilloscope (CRO). This recording system was calibrated with a Bruel and Kjaer Model 4230 120 dB pistonphone and a Tektronix Model 2901 crystal controlled time mark generator.

The microphone was oriented at grazing incidence (90°) to the test unit to ensure that side-on pressure was measured and to obtain the widest possible frequency response [12]. All the tests were conducted in a concrete cell measuring 6.0 m×6.0 m×4.0 m. The microphone was positioned 1.0 m from the floor and walls and 1.0 m from the test unit (Fig. 1). The distance of 1.0 m between the microphone and the test unit is the proposed distance for defining the potential damage to hearing by impulse noise [5] while the choice of 1.0 m between the test unit and the floor and walls was used to minimize ground, wall or ceiling reflections.

The experimental quantities that are important in determining the physical and physiological effects of a blast wave are the peak overpressure, P_{max}, and the positive phase impulse $I^+ = \int_0^{t^+} P dt$ where t^+ is the duration of the positive pressure pulse [5,6]. The peak overpressure P_{max}, was determined directly from the pressure–time trace and I^+ was obtained from the area under the digitized pressure–time trace.

Results and discussion

Experimentally determined values for the mean P_{max} and the mean I^+ for all the materials studied are given in Table 1. These represent the average of between two and five separate results. The standard deviation of each material tested is also given in Table 1. The large values for the standard deviations are

TABLE 1

Blast wave characteristics of 200 mg of selected primary explosives and pyrotechnic mixtures, measured at 1 metre

Energetic material	Abbreviation	Mean P_{max} (kPa)	σ (kPa)	Mean I^+ (Pa s)
Primary explosives				
6-Diazo-2,4-dinitrophenolate	DDNP	3.6	0.19	0.38
5-Nitro-2-picryltetrazole	PNT	4.6	0.13	0.66
Normal lead styphnate	LS	3.0	0.16	0.25
Potassium 4,6-dinitrobenzofurazan 1-oxide	KDNBF	4.1	0.20	0.56
1,2-bis(5,5'-tetrazolato)hydrazine	HAT	3.4	0.15	0.43
Tetracene	TETRACENE	3.2	0.04	0.32
Tetracene/Na_2CO_3 (90:10)[a]	TET/NC	2.8	0.16	0.24
Tetracene/$NaNO_2$ (90:10)[a]	TET/NN	2.8	0.13	0.23
2-Methyl-5-nitrotetrazole	MNT	4.5	0.11	0.65
Potassium 6-azido-2,4-dinitriphenolate	KAZDNP	3.5	0.17	0.44
Pyrotechnics				
Potassium perchlorate/aluminium/acroid resin (59:40:1)[a]	MRL(X)210	3.9	0.20	0.82
Potassium perchlorate/magnesium/aerosil (59:40:1)[a]	MRL(X)206	3.4	0.35	0.46
Potassium nitrate/tetranitrocarbazole (60:40)[a]	SR112	0.8	0.15	0.06
High explosives				
2,4,6-Trinitrotoluene[b]	TNT	5.1	–	0.73

[a]Proportions by weight.
[b]Data from [2] using a different apparatus.

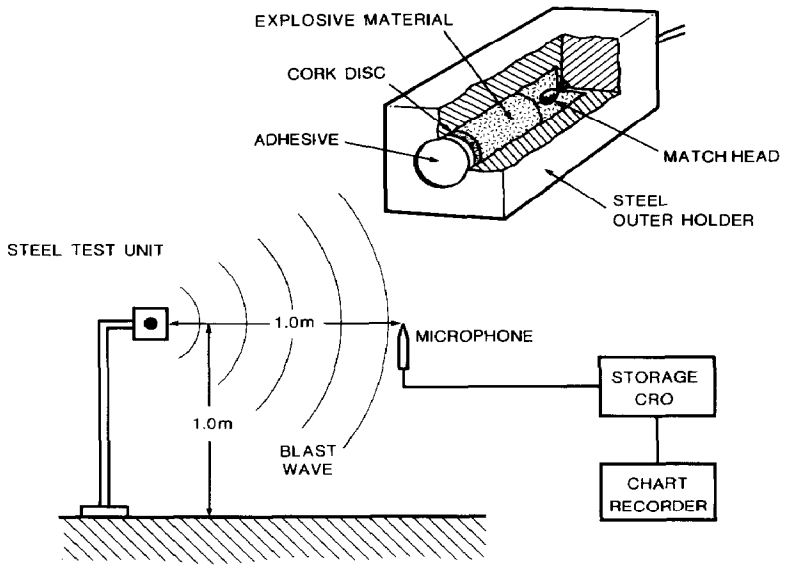

Fig. 1. Experimental set-up.

principally due to the nonreproducible sealing of the test unit with the cork disc and the adhesive (Fig. 1). This resulted in a range of values for both P_{max} and I^+ for each test.

Both P_{max} and I^+ for the series of primary explosives studied, cover a relatively narrow range (Table 1). The highest values for both parameters were observed for PNT (4.6 kPa and 0.66 Pa s respectively) while LS exhibited the lowest values (3.0 kPa and 0.25 Pa s respectively). The addition of 10% of inert material ($NaNO_2$ or Na_2CO_3) to tetracene resulted in a decrease in P_{max} by approximately 10% while I^+ decreased to a greater extent due to the added effect of the corresponding decrease in t^+ from 0.20 ms to 0.17 ms.

The P_{max} and I^+ values for the pyrotechnic compositions covered a very wide range. MRL(X)210 exhibited blast characteristics (P_{max} 3.9 kPa, I^+ 0.82 Pa s) greater than several of the primary explosives and similar to KDNBF. It should be noted that although the P_{max} values are similar, MRL(X)210 exhibits a significantly larger I^+ which may be due to the after-burning of the aluminium, causing an increase in t^+. This behaviour has been observed with aluminized explosives [13]. SR112 gave a very low P_{max} and I^+ (0.8 kPa and 0.06 Pa s) due to the lower volume of gas produced on initiation and the lower temperature of the reaction products [14].

Table 1 also contains data for TNT obtained by Baker et al. [2]. This is a side-on value obtained for a single free air blast and is included for comparison purposes. No attempt was made to determine values for P_{max} and I^+ for TNT using the experimental arrangement detailed above; initiation could not be

achieved, as would be expected, using such a low energy initiation source as a fusehead and the dimensions of the test unit were below the critical diameter of TNT.

Given that the criteria for evaluating safety levels and blast damage are a function of both P_{max} and I^+, then there appears to be no clear separation between the hazards associated with these primary explosives and pyrotechnic compositions. It should be noted, however, that reducing the confinement of the compositions would decrease the value of P_{max} and I^+.

It has been shown from studies of secondary explosives that P_{max} and I^+ measurements made from large scale explosions can be scaled to predict the air blast characteristics of smaller scale explosions using eqns. (1–3):

$$P_{max} = f(R/W^{1/3}) \tag{1}$$

$$I^+/W^{1/3} = g(R/W^{1/3}) \tag{2}$$

where W is the mass of material, R is the distance from the explosion and $R/W^{1/3}$ is termed the scaled distance.

These scaling laws are used for estimating realistic values of P_{max} and I^+ which are useful in predicting blast profiles and the design of protective systems to minimize personnel or material damage.

To examine the use of these scaling laws for primary explosives and pyrotechnics, measurements of P_{max} and $I^+/W^{1/3}$ as a function of scaled distance were carried out for selected materials. Change in the scaled distance was achieved by variations in both the mass of material from 200 mg to 1000 mg (at 1.0 m, $R/W^{1/3}$ ranged from 10 m kg$^{-1/3}$ to 17 m kg$^{-1/3}$) and variations in the distance from the explosion from 0.75 m to 2.5 m (for 200 mg of material, $R/W^{1/3}$ changed from approximately 13 m kg$^{-1/3}$ to 43 m kg$^{-1/3}$). Figures 2 and 3 graphically present the results for P_{max} and $I^+/W^{1/3}$ respectively for selected primary explosives (tetracene and PNT), pyrotechnics (SR112 and MRL(X)210), and TNT [2].

Figure 2 shows that P_{max} for these materials may be represented as a function of the scaled distance in a similar manner to that for TNT (eqn. 1). There is also good agreement between the two sets of results obtained by altering the mass of explosive or pyrotechnic and those obtained by altering the distance from the explosion. Figure 2 also verifies the previous conclusion that no clear separation between these energetic materials exist in terms of P_{max}. In fact, the "order of ranking" alters with the value of the scaled distance. For example, tetracene exhibits lower P_{max} values than MRL(X)210 for scaled distances between 10 m kg$^{-1/3}$ and 25 m kg$^{-1/3}$. However, beyond 25 m kg$^{-1/3}$, tetracene exhibits slightly larger values of P_{max} than MRL(X)210.

Figure 3 verifies that eqn. (2) can be used to describe the variation in $I^+/W^{1/3}$ (and so I^+) with scaled distance. Tetracene exhibitis good agreement between the variation in mass results and the variation in distance results.

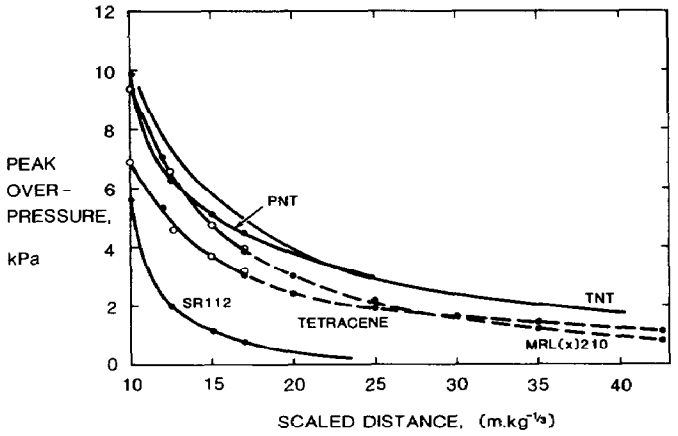

Fig. 2. Peak overpressure versus scaled distance for TNT, primary explosives and pyrotechnics; ○ variation in the mass of material, ● variation in the distance from explosion.

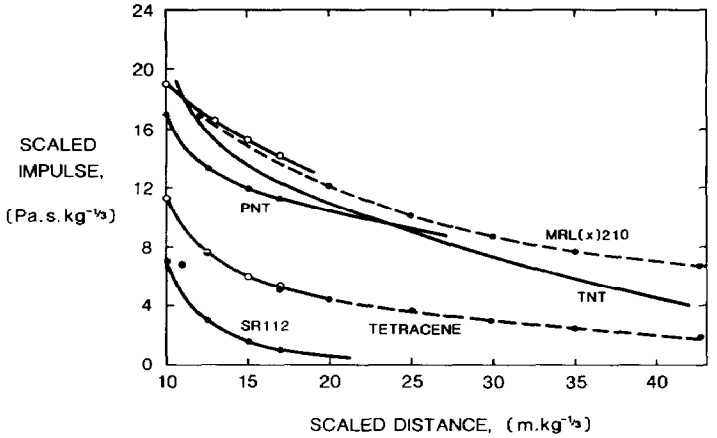

Fig. 3. Scaled impulse versus scaled distance for TNT, primary explosives and pyrotechnics; ○ variation in the mass of material, ● variation in the distance from explosion.

MRL(X)210 does not, however, show such good agreement. The separation between these results for the different materials is more noticeable with MRL(X)210 exhibiting greater $I^+/W^{1/3}$ values than TNT for scaled distances greater than 10 m kg$^{-1/3}$. Tetracene shows significantly lower $I^+/W^{1/3}$ values than MRL(X)210 due to its faster reaction rate and hence smaller value of t^+ (0.20 ms and 0.42 ms respectively).

A technique that is frequently used with secondary explosives to evaluate damage effects of blast waves on structures is the TNT equivalence [1–3,8]. The TNT equivalence is the ratio of the mass of TNT to the mass of explosive that will produce the same terminal effect (usually P_{max}) at the same distance, i.e. equating the blast wave strength to that of an equivalent mass of TNT.

TNT equivalence is not normally used for primary explosives or pyrotechnics as they have not been considered to be energetic enough to be of concern although values are sometimes reported for hazard rating purposes [11]. However, particularly with pyrotechnics, confinement of the composition (as in Fig. 1) can cause a more rapid reaction before rupture of the sealing disc, leading to large values of P_{max}.

Using the P_{max} values from Fig. 2, TNT equivalence for some of the primary explosives and pyrotechnic mixtures are given in Table 2. Values for other materials have been included for reference. Table 2 shows that both the primary explosives and the pyrotechnic compositions have TNT equivalency values significantly below that for TNT. Again it is also evident that there is no clear separation between the primary explosives and the pyrotechnics, with PNT exhibiting the greatest TNT equivalence followed by MRL(X)210, tetracene and SR112.

However, Fig. 4 shows that the values of TNT equivalence are not necessarily constant with scaled distance. The primary explosives, which typically have high reaction rates exhibit an almost constant TNT equivalence, while pyrotechnics, which generally have lower reaction rates, show a definite decrease in TNT equivalence with scaled distance. Variation of the TNT equivalence has previously been attributed to the different ignition and combustion characteristics of different materials or multiple shock waves coalescing with distance [8]. No multiple reflections were observed on the pressure–time records. It is more likely that the decrease in TNT equivalence is due to the difference in the combustion mechanisms between explosives and pyrotechnics.

Two additional factors need to be considered. First, in the case of the pyrotechnic materials, particularly MRL(X)210, part of the reaction occurs outside the test unit where some of the aluminium may react with atmospheric

TABLE 2

TNT equivalence values for selected energetic materials [2,11]

Material	TNT equivalence
RDX	1.18
Violet smoke composition	0[a]
$Mg/NaNO_3$ flare	0.47[a]
Lead styphnate	0.42
SR112	0.12[b]
Tetracene	0.42[b]
MRL(X)210	0.60[b]
PNT	0.79[b]
TNT	1.00

[a]At scaled distance 3.5 m $kg^{-1/3}$.
[b]Average between scaled distances 10 m $kg^{-1/3}$ and 25 m $kg^{-1/3}$.

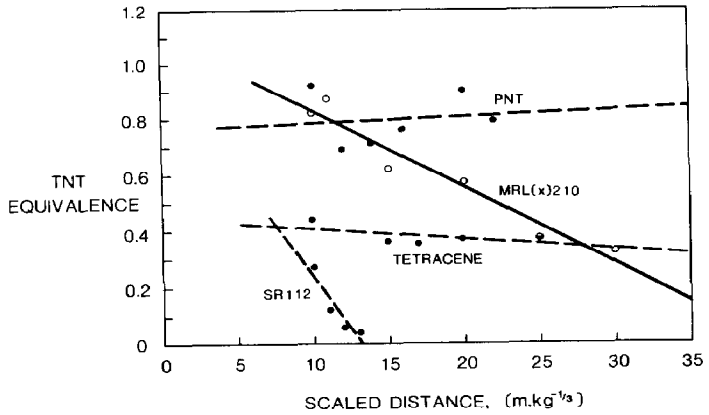

Fig. 4. Variation in TNT equivalence with scaled distance for selected primary explosives and pyrotechnics.

oxygen. Second, some of the energy that would otherwise be available to the blast wave is consumed in rupturing the test unit sealing. A minimum pressure would then be required to rupture the seal, giving a higher value of P_{max} at small scaled distances and higher TNT equivalence.

It should be noted that for materials such as pyrotechnics and primary explosives which may be considered marginally explosive, the magnitude of the blast wave (both P_{max} and I^+) is heavily dependent on the confinement of the composition and its burning etc. If the test unit geometry or composition were altered from those used here, then different blast characteristics would be observed. High explosives (such as TNT, RDX, etc.) however, usually detonate producing a blast wave essentially regardless of confinement provided the diameter of the sample exceeds the critical diameter of the explosive.

The TNT equivalence value depends on many factors and is not an entirely exact procedure. Therefore, only approximate conclusions can be drawn. Damage to personnel exposed to blast waves is also dependent on the magnitude of I^+ which the TNT equivalence does not take into account. Therefore the use of TNT equivalence data with many pyrotechnics which exhibit low values of P_{max} but high values for I^+ may lead to unreliable conclusions.

Conclusions

The peak overpressure and positive impulse of primary explosives and pyrotechnic compositions may be predicted using simple scaled distance formulae as derived for secondary explosives. The relationships hold, at least for weights ranging from 200 mg to 1000 mg and distances from 0.5 m to 3.0 m.

Both primary explosives and pyrotechnics exhibit a range of peak pressures and impulses which may be of the same order of magnitude as TNT.

The TNT equivalence values are not constant and may be significantly dependent on the mass of material and distance from the explosion. The validity of defining a single value of TNT equivalence is therefore questioned as are judgements of safety and damage risk criteria based on a single TNT equivalence value derived from peak overpressure values for these materials.

Overall, there is no clear separation between the blast characteristics of these primary explosives or pyrotechnic compositions and they should be treated as equally hazardous materials.

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