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STUDIES ON THE THERMAL BEHAVIOUR OF DETONATING FUSE AND DETONATORS

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Investigations of the thermal stability of detonating fuse containing 10 g pentaerythrol tetranitrate (PETN) revealed that the cord burnt under unconfinement at 403 K. Under confinement in a steel pipe or copper tube there was a partial detonation at 403 K. In order to characterize the thermal stability of PETN and pyrotechnic composition used in fuse head of electric detonators differential thermal analysis (DTA) was used.

The electric detonators of aluminium cell and copper cell were heated from ambient temperature to 373 K at an average rate of 0.4 deg/min. The rate of heating was increased gradually to 1.5 deg/min till explosion. The detonation temperature varied between 373 K and 375 K.

The impact and friction sensitivity of detonating fuse was poor. There was no detonation when a 5 kg hammer was repeatedly hit over the fuse from a height of one metre. There was no detonation when the detonating fuse was rubbed by a blunt edge of steel plate till it was smashed.

The main objective of the investigation was to gather information regarding safety while using detonators and detonating fuse in fire areas of mines where blasting is resorted in hot holes. Chattopadhyay and Seshan [1, 2] investigated the thermal stability of commercial explosives using differential scanning calorimetry. It was revealed that solid explosives had the least stability, the emulsions the highest, the water gels falling in between. Decomposition or explosion of explosives is markedly influenced by the presence of various ingredients and by the nature of confinements. Makashir and Kurian [3] determined the activation energy of PETN and studied the effect of oxides of nickel, lead and aluminium on the decomposition temperature using differential scanning calorimetry. Hemmila and others [4] determined the kinetic parameters of 2,4,6-trinitrotoluene using DTA and TG method and computed the kinetic parameters using the Kissinger [5], the Ozawa [6, 7] and the Rogers and Morris [8] equations.

The authors investigated the thermal stability of detonators and detonating fuses and also the impact sensitivity of detonating fuse. A Shimadzu differential thermal analyzer model DT–30 was used to investigate the ignition temperature, activation energy and reaction rate constant of PETN and pyrotechnic compositions which were used in electric delay and instantaneous detonators.

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The peak temperature of a DTA curve depends on the rate of heating. It was used to compute the activation energy, frequency and reaction rate constant. The activation energy, rate constant and frequency factor were computed with the help of the Ozawa equation [6].

Experimental set-up

Kinetic parameters

PETN and a fuse head pyrotechnic composition were taken from detonating fuse and fuse head of electric detonators. DTA curves were recorded (Figs 1–2) with a Shimadzu differential thermal analyzer model DT–30. Explosives weighing 25 to

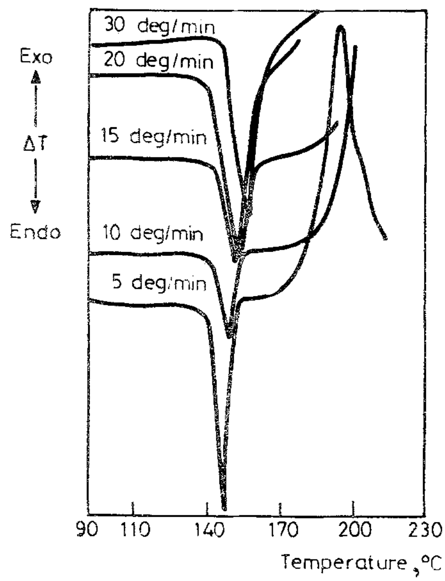

Fig. 1 DTA curve for PETN at different rates of heating

26 mg were packed in aluminium foil crucibles (volume 0.04 ml). The reference material was finely powdered α-Al_2O_3. The heating rates applied were 5, 10, 15, 20 and 30 deg/min. Results of investigation are summarised in Table 1a and 1b and Fig. 3.

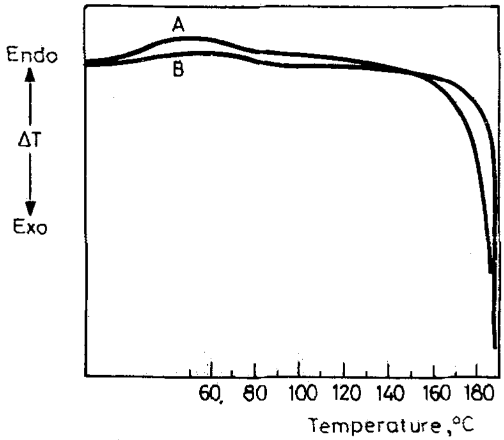

Fig. 2 DTA curve for fuse head composition

Table 1(a) Thermal properties of PETN and a fuse head composition

Heating rate, deg/min	Ignition temp., K	Activation energy, kJ/mol	Frequency factor, mol/min	Rate constant at 445.9, mol/min	Correlation coefficient
5	436.02				
10	442.00	145.6	1.075×10^{17}	1.58	0.99
15	448.7				
20	451.2				
30	452.0				

Table 1(b) Thermal properties of fuse head composition

Explosive type	Ignition temp., K
A-10	323
B-10	388

Thermal behaviour of detonators

Detonators were placed in a sand filled steel pipe of 50 mm I.D. and 25 cm long. The steel pipe was then placed in a cement asbestor tubular furnace of 80 mm I.D. and 30 cm long. The arrangement is shown in Fig. 4. The heating rate was controlled manually with regulator. A Cr–Al thermocouple was attached to the detonator and the temperature was monitored using a temperature indicator. The detonators were heated from ambient temperature to 100° at an average rate of 0.4 deg/min. The rate of heating was increased gradually to 1.5 deg/min till

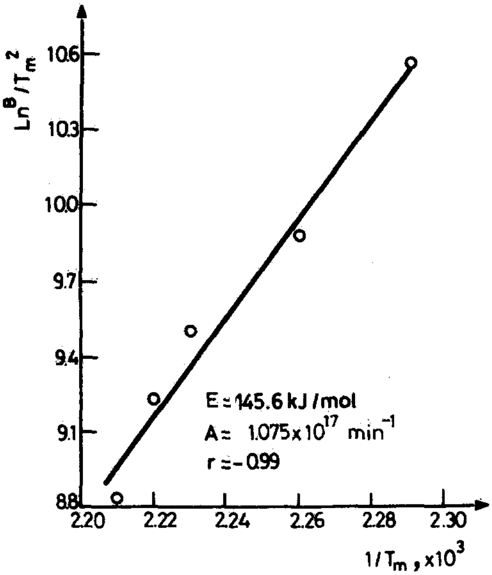

Fig. 3 Plot for PETN ignition in DTA. $E = 145.6$ kJ/mol, $A = 1.075 \cdot 10^{17}$ min^{-1}, $r = -0.9900$

explosion. The explosion temperature varied between 100° and 138°. The investigations indicated the effect of the rate of heating on the explosion temperature of detonators. The results are tabulated in Table 2.

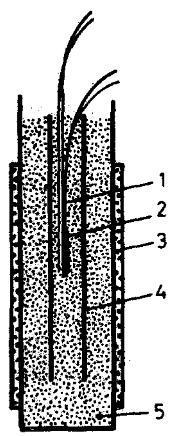

Fig. 4 Heat sensitivity test of a detonator. 1: thermocouple, 2: detonator, 3: furnace, 4: steel pipe, 5: sand

Table 2 Explosion temperature of instantaneous aluminium detonators and delay detonators

Heating rate, deg/min	Explosion temp., K	Remarks
Manufacturer "A"		
0.4	373	Exploded after 2 hours
0.6	391	Exploded within 15 minutes
1.3	408	Instantaneous explosion
1.5	411	Instantaneous explosion
Manufacturer "B"		
0.5	373	Exploded after 1.5 hours
1.5	403	Instantaneous explosion
Delay detonators		
2	385.5	Instantaneous explosion
4	393	Instantaneous explosion
5	398	Instantaneous explosion

Thermal sensitivity of a detonating fuse

A detonating fuse (3 m long) was placed in a tubular furnace of 80 mm I.D. and 50 cm length. 2 m length of the fuse was coiled. The coiled portion was hanged inside the furnace and the other end of the fuse was taken out of the furnace through an open end. The tubular furnace was heated to determine the ignition or explosion temperatures. The temperature was recorded using a calibrated thermistor which was attached to the fuse coil. The heating rate was controlled with a regulator.

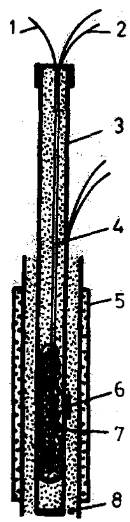

Fig. 5 Heat sensitivity test of a detonating fuse. 1: fuse, 2: thermistor, 3: steel pipe, 4: stemming, 5: furnace, 6: thermistor, 7: detonating fuse, 8: sand

Similar investigations were carried out under the confined conditions. The coiled portion of fuse was placed inside a steel pipe of 25 mm I.D. and 1.5 m long with one end closed. The coil of the fuse was near to the closed end. The steel pipe was filled with dry sand and closed with a cap. A thermistor was glued to the fuse coil inside the steel pipe. The arrangement is shown in Fig. 5. The results of the measurements are summarised in Table 3.

Table 3 Thermal sensitivity of detonating fuse

Type of test	Temperature, K	Observations
Unconfined	403 ± 10	Portion of detonating fuse inside the furnace burnt and the portion outside the furnace was unaffected.
Confined in steel pipe	403 ± 10	Bursting of steel pipe in the portion of detonating coil. The coiled portion of fuse was consumed, However, the portion of fuse outside the steel pipe along with a small length inside the pipe covered with sand remained unaffected.

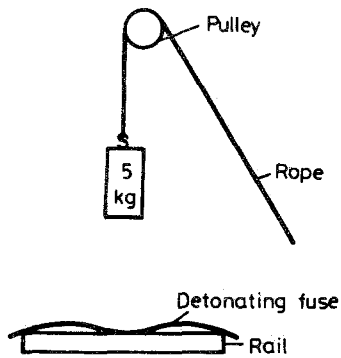

Fig. 6 Impact sensitivity test of a detonating fuse

Impact sensitivity of a detonating fuse

The conventional "fall hammer" apparatus was used to determine the sensitivity of the detonating fuse. 20 mg powder or 5 mm length of fuse sample was placed in between two rollers in a socket. Steel hammers weighing 1, 5 and 10 kg were dropped from different heights till the detonation or explosion was recorded. For determining the impact sensitivity of the detonating fuse 25 cm length of fuse was placed on a steel rail and 5 and 10 kg hammers were dropped vertically on the fuse from a height of one metre. The results of these studies are summarised in Table 4.

Table 4 Impact sensitivity of detonating fuse and PETN powder

Weight of falling hammer, kg	Test sample	Observation
1.0	PETN	Detonation at 35 cm height
5.0	Detonating fuse	Detonation at 35 cm height
5.0	A 25 cm length of fuse placed on a steel rail.	Hammer was dropped from a height of 150 cm. No detonation was observed. The fuse smashed and flattened at the point of impact.
10.0	—do—	Detonation at 90 cm height Detonation at 80 cm height No detonation when hammer was dropped from a height of 60 cm. However, detonation was localised only at the point of impact. The remaining portion of the detonating fuse was unaffected.

Results and discussion

The thermal investigation of commercially available detonators and detonating fuse indicated that for safe blasting the detonators should not be inserted in hot blast holes where the temperature exceeds 80°. However, the detonating fuse can be used in hot holes where temperature is less than 100°. Use of detonators and detonating fuses in hot holes and fire area where the temperatures are in excess as mentioned above might lead to premature detonation resulting in serious accidents. In the recent past a premature detonation took place while charging hot holes in a mine causing the death of some miners. Thermal sensitivity investigations indicated that the instantaneous detonators of manufacturer "A" were less sensitive when compared to those produced by manufacturer "B". The explosion temperature of delay detonators was lower than that of instantaneous detonators.

Investigations revealed that the impact sensitivity of the detonating fuses studied was extremely poor. When the fuse was placed on a rail and repeatedly hit by dropping a 5 kg hammer from a height of one metre there was no detonation. Detonation was not observed either when the detonating fuse was cut by rubbing with the blunt of a G.I. sheet and holding the edge of the steel sheet on the fuse and hitting over it.

DTA investigation of pyrotechnic compositions used in fuse head of electric detonators indicated an ignition at 393 K and explosion at 413 K when the rate of heating was 10 deg per minute. The explosion temperature of the detonator included the combined effect of fuse head, ASA composition and PETN as base charge under confinement.

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Zusammenfassung — Untersuchungen der thermischen Stabilität von Sprengschnuren mit 10 gm^{-1} PETN zeigten, daß die Schnur frei bei 403 K verbrennt. Unter Abschluß in einem Stahl- oder Kupferrohr tritt bei 403 K eine partielle Detonation auf. Zur Charakterisierung der thermischen Stabilität von PETN und von pyrotechnischen Mischungen, die in Zünderköpfen von elektrischen Sprengkapseln verwendet werden, wurde Differentialthermoanalyse (DTA) angewendet. Die elektrischen Sprengkapseln von Aluminium- und Kupferzellen wurden mit einer durchschnittlichen Aufheizgeschwindigkeit von 0.4 Grad/min von Raumtemperatur auf 373 K erhitzt. Die Aufheizgeschwindigkeit wurde bis zur Explosion allmählich auf 1,5 Grad/min erhöht. Die einzelnen Detonationen erfolgten bei einer Temperatur zwischen 373 und 375 K. Die Stoß- und Reibempfindlichkeit der Sprengschnur war gering Bei einem mehrmaligen Einwirken eines 5 kg-Hammers aus einer Höhe von 1 m erfolgte keine Detonation. Bei Reiben mit der unscharfen Kante einer Stahlplatte bis zur Zerstörung erfolgte keine Detonation.

Резюме — Исследование термоустойчивости детонирующего запала, содержащего 10 $гм^{-1}$ PETN, показали, что в открытом пространстве шнур зажигался при 403 K. При помещении его в стальную или медную трубу происходила частичная детонация его при температуре 403 K. Для определения термоустойчивости PETN и пиротехнического состава, используемого в головке запала электрических детонаторов, был использован дифференциальный термический анализ. Электрические детонаторы с алюминиевой и медной ячейкой нагревались от комнатной температуры до 373 K со средней скоростью нагрева 0,4°/мин. Затем скорость нагрева постепенно увеличивали до 1,5°/мин до самого взрыва. Температура детонации менялась между 373 и 375 K. Малочувствительным оказался детонирующий запал к ударному действию и трению. Детонация не происходила даже при многоразовом ударе 5 кг молотом по нему с высоты 1 м. Детонация не происходила также и тогда, когда запал подвергался трению до его полного разрушения.