Letter

Study on underwater blasting energy and flame characteristics of detonators and detonating fuse

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Abstract

Explosives and its accessories are the cheapest source of energy to excavate the rock for mining industry. On detonation, explosives and blasting accessories produce various types of energy like shock, gas, light, heat, sound, seismic etc,. A good energy product enhances the production and productivity of the mine. It has been experienced that the open pit mining operations are feasible up to 90 m depth and below this it is neither economical nor technically convenient. Therefore, it is essential to dig out the coal through underground mining operations below this depth to fulfill the demand of power. An underground coal-mine contains methane air mixture and coal dust which are highly inflammable in nature. During blasting they may ignite and causes accidents. Every year, in India and abroad many accidents occur in underground coal mines during the firing of explosive and its accessories. The flame characteristics and detonation temperature of explosives and its accessories are mainly responsible for the ignition of methane air mixture and coal dust. In this paper authors have studied the under water blasting energy and flame characteristics of detonators and detonating fuse which are used in underground mining operation, in detail.

Keywords: Shock energy, Gas energy, Explosion flame, Flame speed, Flame duration.

1. Introduction

Explosives and its accessories are the main tools in mining excavation work. The efficiency of an explosive depends upon its composition which also determines its energy content. Explosive properties [1] such as density, strength and rate of reaction play an important role for the rock fragmentation. Detonators and detonating fuses have a special role to detonate the explosive charges. They can donate a minimum amount of energy to the acceptor for detonation. In mining operations two categories of detonators are in use: (i) Aluminum tube detonators are highly incendive and are used in the surface mine blasting (ii) Copper - tube detonators are less incendive [2] and they are used in the underground coal or metal mines.

In 1958, Taylor and Gay [2] illustrated the modern detonators and their design. The short delay detonators contained PETN as a base material and a priming charge consisting of a mixture of lead styphnate, lead azide and aluminum powder which are consolidated together along with a binding material by pressure. The delay element generally consists of mixture of red lead and silicon but other compositions are also used. The delay composition burns with certain speed, evolving little gas to maintain the delay intervals and sufficient energy to detonate the base charge.

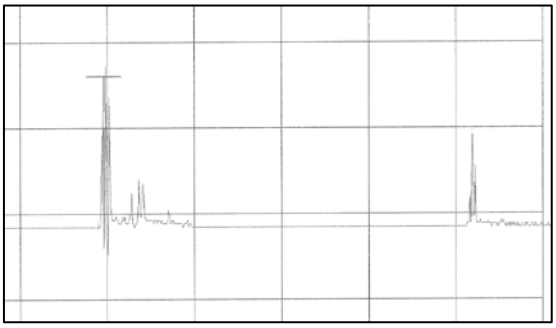
The detonating fuse is a simple and safe device for initiating cap-sensitive commercial explosives. It consists of a core of PETN with a covering of rayon and PVC coating and upon initiation it burns giving velocity of detonation in the range of 6500 ± 200 ms^{-1}. In India, 10 gm^{-1}, 5.5 gm^{-1} and 3.5 gm^{-1} detonating fuses are available for earth excavation. They have high velocity of detonation and produce longer flame length and flame duration. The detonating fuse with core PETN charge of 5.5 gm^{-1} and 3.5 gm^{-1} are used as permitted detonating fuse (uniring blasting method) in underground mines. In permitted type detonating fuse flame and energy retardant agents are used to optimize / reduce the explosion flame and energy of detonation.

On detonation, shock and gas energy produced is the maximum in explosive energy, which is about 70 % of the total energy. The shock and gas energy of detonators and

Table 1 Shock and gas energy of various types of detonators used in mining operations.

Detonator Type	Tb ms	Eb KJ	Es KJ	Total Energy (Eb + Es) KJ
Al-instantaneous	21.50	0.98	21.21	22.19
Cu-instantaneous	21.50	0.98	11.69	12.67
Delay-1	23.00	1.20	27.47	28.67
Delay-2	23.00	1.20	47.15	48.34
Delay-3	24.00	1.46	49.88	51.34
Delay-4	25.00	1.86	58.64	60.50
Delay-5	19.00	0.66	61.21	62.21

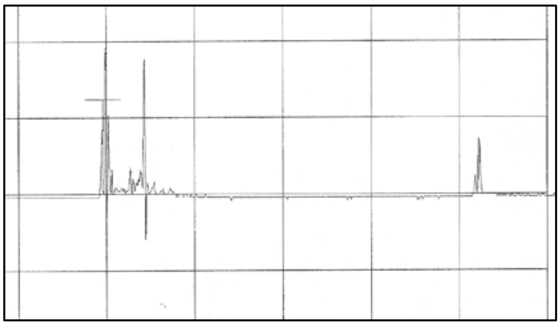
1 volt / div.



5 ms / division

Fig. 1 Shock and gas waves of Al- instantaneous detonator.

1 volt / div.



5 ms / division

Fig. 2 Shock and gas waves of Cu- instantaneous detonator.

Table 2 Shock and gas energy of detonating fuse.

Detonating Fuse	D. Fuse length m	Tb ms	Eb KJ	Es KJ	Total Energy (Eb + Es) KJ
10 gm^{-1}	0.25	42.50	5.68	2.92	8.60
10 gm^{-1}	0.50	50.00	12.30	6.30	18.60
10 gm^{-1}	1.00	62.50	23.63	13.96	37.59
10 gm^{-1}	1.50	70.50	36.93	2.29	57.22
10 gm^{-1}	2.00	78.00	49.36	27.36	76.72

detonating fuses were measured by using underwater test, which is the best suitable method to calculate the maximum energy content in the explosives. Bhushan and et al. [3] measured the explosive energies in 1986. During a detonation in high explosives, the shock energy at the reaction front travels through the explosive before the gas energy is released. The Cole [4] equation was used to measure the shock energy, gas energy, and time. Jose A. Sanchidrian [5] studied numerical modeling of underwater blasting in 1988.

The high-speed photography is the powerful diagnostic technique to study and analyze the flame generated by explosives and detonators. R.F Chiapetta et al. [6] used the high-speed motion pictures in 1983 to record the blast events in the mining industry. T. Urbanski [7] illustrated the flame characteristics of picric acid and NG-based explosives. Pingua and et al. [8] have studied the flame characteristics of permitted NG- based, slurry and emulsion explosives. The High-speed photography system is a proven and very useful research tool for studying the dynamics of blasting as well as flame characteristics of explosives. In this paper High Speed Video system (Model AG-455 MB, Panasonic) was used to measure the explosion flame of detonators and detonating fuses.

2. Experimentation

2.1 Shock and gas energy of detonators

The instantaneous Aluminum, copper and delay detonators of zero, 1, 2, 3, 4 and 5 series were taken for the underwater explosion test. The tourmaline sensor model 138A 01 (M/s PCB Piezotronics, Inc. New York, USA) was used to measure the value of bubble oscillation period (Tb), shock energy (Es) and gas energy (Eb). This sensor was connected to the digital oscilloscope (Model 2220 Tektronix, USA) and detonation waves were recorded in Oscilloscope to print through the printer. The shock and gas pressures of Al-instantaneous detonator and Cu-detonator are shown in Fig. 1 and 2. The other forms of energy like seismic, heat, sound, light etc. can not be measured with the tourmaline type sensors. The energy values of shock and gas were calculated with the help of Cole equation and given in Table 1.

Table 3 Flame characteristics of Al- detonator.

Detonator	Flame length Primary m	Flame length Seconary m	Flame speed ms^{-1}	Flame duration ms
Al-instantaneous	0.10 ± 0.01	0.50 ± 0.01	2.00	16
Delay-1	0.40 ± 0.01	0.22 ± 0.01	1.60	16
Delay-2	0.50 ± 0.01	0.20 ± 0.01	2.00	14
Delay-3	0.50 ± 0.01	0.23 ± 0.01	2.00	18
Delay-4	0.60 ± 0.01	0.24 ± 0.01	2.40	14
Delay-5	0.62 ± 0.01	0.24 ± 0.01	2.48	16

Table 4 Flame characteristics of copper detonator.

Detonator	Flame length Primary m	Flame length Seconary m	Flame speed ms^{-1}	Flame duration ms
Instantaneous	0.09 ± 0.01	Nil	0.36	6
Zero-delay	0.06 ± 0.01	Nil	0.24	8
Delay-1	0.05 ± 0.01	Nil	0.20	10
Delay-2	0.07 ± 0.01	Flame dispersed with splinters of cu-tube	0.28	12
Delay-3	0.065 ± 0.01	-Do-	0.26	14
Delay-4	0.07 ± 0.01	-Do-	0.28	12
Delay-5	0.15 ± 0.01	-Do-	0.60	10

Fig. 3 Explosion flame of Cu- zero delay detonator.

Fig. 4 Explosion flames of Al delay –1 detonator.

2.2 Shock and gas energy of detonating fuse

The different length of 10 gm^{-1} detonating fuse was cut off from the main reel for underwater explosion test. The length of fuse reels were 0.25 m, 0.5 m, 1.0 m, 1.50 m and 2.0 m respectively. The different lengths of detonating fuse were detonated at the definite depth of water and released shock energy (Es), gas energy (Eb) and bubble oscillation time (Tb) were recorded in the Oscilloscope. The results of 10 gm^{-1} detonating fuse of different lengths are given in the Table 2.

2.3 Flame characteristics of detonators and detonating fuses

2.3.1 Flame characteristics of detonators

The aluminium, copper and copper coated delay detonators of zero, 1, 2, 3, 4, & 5 series were taken for the measurement of flame length and its duration. The detonators were fired one by one and explosion flame was recorded using high-speed video system. Each event was repeated 5 times and the values of flame length and duration of flame were recorded and analyzed using high speed video system. The experimental results are shown in Table 3 and Table 4 for aluminum and copper detonators respectively. The flame characteristics of Cu- zero delay and Al-delay 1 detonators are shown in Fig. 3 and Fig. 4 respectively.

2.3.2 Flame characteristics of detonating fuses

The 1 m length of detonating fuse of 10 gm^{-1}, 5.5 gm^{-1} and 3.5 gm^{-1} were cut off from the main fuse reel and fired. The explosion flame was measured with the help of high-speed video recording system. Each event was repeated 5 times. The flame characteristics of 10 gm^{-1}, and 5.5 gm^{-1} fuse reel are shown in the Fig. 5 and 6. The recorded flames were analyzed with the help of High Speed Video System and results are shown in Table 5.

Fig. 5 Explosion flame of 10 gm^{-1} detonating fuse.

Fig. 6 Explosion flame of 5.5 gm^{-1} detonating fuse.

Table 5 Flame characteristics of 10 gm^{-1}, 5.5 gm^{-1} and 3.5 gm^{-1} length PETN based detonating fuse.

Detonator fuse	Flame length		Flame speed ms^{-1}	Flame duration ms
	Primary m	Seconary m		
10 gm^{-1}	0.50 ± 0.01	0.80 ± 0.01	3.20	33
5.5 gm^{-1}	0.12 ± 0.01	0.20 ± 0.01	0.48	14
3.5 gm^{-1}	0.10 ± 0.01	—	0.40	10

3. Results and discussions

The experimental results show that the shock energy (Es) in detonators is more than the gas energy (Eb). The shock energy measured in Al – instantaneous detonator was 21.21 KJ and it was 11.69 KJ in Cu-instantaneous detonator. The total energy values of Eb and Es in Al – instantaneous detonator was 22.19 KJ whereas in Cu-instantaneous detonator it was 12.67 KJ. This indicates that Al – detonators are of higher strength than Cu-detonators. In all Cu-delay detonators it was observed that the shock energy is always higher than the gas energies and total energy values of shock and gas increases with increase in delay number.

The 10 gm^{-1}-detonating fuse is used in the surface blasting. The bubble oscillation period (Tb) increases with the increase in the fuse length. In 0.25 m lengths detonating fuse the Tb value measured was 42.50 ms and with increasing length at 2 m it was 78 ms. The gas energy was higher than shock energy in 10 gm^{-1}-detonating fuse. The gas and shock energy obtained in 1.5 m length of detonating fuse were 36.93 KJ and 20.29 KJ respectively whereas this value was 49.36 KJ and 27.36KJ in 2 m lengths of detonating fuse.

The Al shell detonators are stronger and highly incendive than Cu- coated detonators. The flame characteristics of Al – tube detonators were much more different from the Cu- coated detonators. The Al-tube detonator produces both primary and secondary jetting flames as shown in Fig. 4. In Al – instantaneous detonator the flame speed recorded was 2 ms^{-1} with flame duration of 16 ms. The flame duration of Al detonators were in the range of 14 to 18 ms. The flame speed was found to be in the range of 2 to 2.48 ms^{-1}. In view of above, aluminum detonators cannot be used in underground coalmines as these detonators have higher flame length and flame speed than Cu –coated detonators.

In Cu-coated detonators the primary flame length were recorded in the range of 0.05 m to 0.15 m. The secondary flames were not found in instantaneous, 0-delay and delay 1 detonators but it was observed in other higher delay number detonators. The secondary flames were negligible and dispersed with splinters of Cu tubes in air. The maximum measured flame speed of 0.60 ms^{-1} was found in case of delay 5 detonators. The flame length and speed of cu- coated detonators are comparatively much lower than the aluminium detonators. The flame duration in Cu-coated detonator were found in the range of 6 to 14 ms. The results of experiments are given in the Table 4 which is self explanatory.

The 10 gm^{-1} PETN detonating fuse produced both primary and secondary flames. The recorded spread of primary and secondary flames was 0.50 and 0.80 m respectively with flame speed 3.2 ms^{-1}. The flame duration in 10 gm^{-1} PETN detonating fuse was found 33 ms. The flame speed and duration were much lower in 5.5 gm^{-1} and 3.5 gm^{-1} length detonating fuse. The secondary flames measured were 0.02 m in 5.5 gm^{-1} PETN based detonating fuse whereas it is negligible in 3.5 gm^{-1} PETN based detonating fuse and their flame durations were 14 and 10 ms respectively. The lower explosion flames observed may assign to the incorporation of flame retardant ingredients in the core explosive material in detonating fuse.

4. Conclusion

An experimental results show that the detonators have higher shock energy values, which supplies minimum energy to initiate / boost the cap-sensitive explosives. The more incendiary Al-tube detonators cannot be used in the underground coal and metal mines due to the primary as well as secondary jetting flames with longer flame duration. The Cu-coated detonators produced very less flame duration and flame length and their flame speed is much lower than the Al detonators. The flame duration measured in Cu-detonators was of short period indicating about their safe application for the gassy atmosphere.

In 10 gm^{-1} length detonating fuse, flame produced are more than 0.80 m with flame duration of 33 ms indicating that this type of detonating fuse can not be used in gassy mines. The low energy detonating fuses having short flame duration and length may be used in underground gassy mines.

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