Application of Conducting Composition Fuseheads in Pyrotechnic Devices

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Abstract: *The electrical properties of bridgeless fuseheads were examined. A conducting composition based on the mixture lead styphnate, Viton binder and conductive admixture was used as the fusehead priming mixture. Several types of conducting admixtures, namely two types of natural finely milled graphite and special conducting carbon black, of varying particle size and origin, were used. To produce fuseheads the standard dipping technology for application of the pyrotechnic mixture was used. Fuseheads equipped with a safety shroud and leading wires were installed in a standard aluminum body No. 8 detonator to test the electrical and firing characteristics and determine how these fuseheads will affect the detonator's properties in particular regarding reaction time. The measurements further included determination of electric sensitivity (All-fire energy) and resistance.*

It was found that for production of this type of fusehead is possible to use standard dipping technology without significant change in the technological process, but the presence of binder in the pyrotechnic composition has a considerable influence on the electrical properties. Determination of the reaction times of detonators showed that is possible to reach very short reaction times less than 1 ms. This is approx. 20 times less compared with a detonator (or fusehead) equipped with a standard bridge wire fusehead. This could be advantageous for the many applications where a fast response of the electro-explosive system is required together with low cost and ease of use. Typical of such applications are firework displays and special pyrotechnic effects.

Keywords: *conducting composition, initiator, lead styphnate, electric detonator, fusehead*

Introduction

Electric initiation is the most common method for ignition of explosives or pyrotechnic devices. In this process electrical energy is transformed into heat energy which is then used for heating a small amount of explosive (usually a primary) to its ignition temperature. The heat stimulus obtained is next transformed and amplified depending on the required ignition intensity of the initiator (e.g. shock wave, heat, hot particles). Nowadays several methods of transforming the electrical energy are used. One of these methods involves the use of electrically conductive pyrotechnic compositions (hereafter CC).

The first application of these electro-explosive devices (EEDs) was mentioned by Drekopf[1] regarding electric blasting caps. CCs were then used due to their easy manufacture and simple construction but mainly for their higher resistance to stray electric currents compared to other electric initiators available at that time. Later CC initiators ceased to be used in industrial application due to the difficulty of simultaneous ignition in serial firing circuits.

Interest in CCs grew during WWII as, in order to accommodate the need to increase the rate of fire of aircraft weapons, it was necessary to develop fast and powerful but also small and resistant electric primers. Later CC systems were applied to other military pyrotechnic devices. But mostly, up to now, CCs have been used in primers for small range ammunition. A characteristic construction feature of these devices is the absence of galvanic connection between two electrodes (e.g. a bridge wire).

The connection between the two electrodes is made by a pyrotechnic composition containing an admixture of an electrically conductive material (e.g. powdered metals, graphite, carbon black) with the pyrotechnic composition. The characteristic

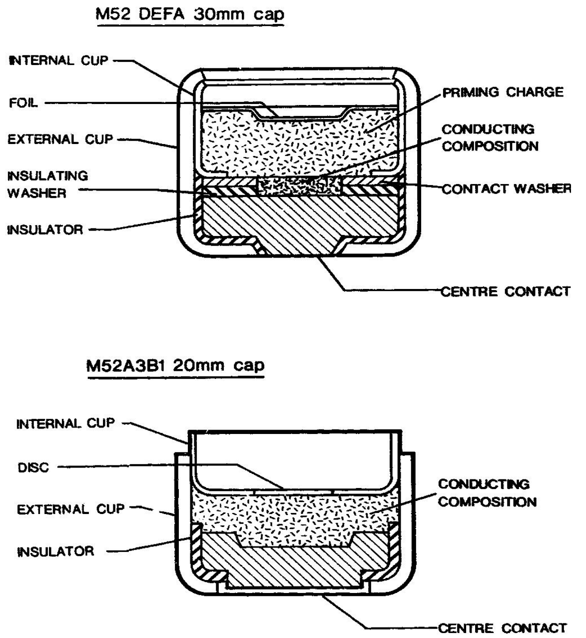

Figure 1. *Illustration of the characteristic construction of CC primers.*

configuration of CC primers is shown in Figure 1.

During the 1980s intensive research[2,3] was carried out into the properties and factors affecting performance and safety, due to worries resulting from unexpected ignition or defective function due to the high sensitivity of these devices. Sheridan[3] presented results showing a significant influence of the type and particle size of the conductive admixture on the reaction time and sensitivity of CC primers. This work also showed that by using graphite of different origin (natural or synthetic) and/or mixtures thereof it is possible to markedly change the parameters of CC primers.

This fact has been validated also by other authors. Spear[4] focused his work on studying the influence of the particle size of lead styphnate on the electrical parameters, namely the electric resistance. Examples of the pyrotechnic priming formulations used in the CC primers in the current ordnance are presented in Table 1. From Table 1 it is evident that main component of all the CCs is lead styphnate (LS), which produces the necessary acceleration, brisance and heat sensitivity. Also it is clear that finely milled graphite and conductive carbon black are mostly used in the conducting admixtures. Several other types of conductive admixture, and how to create conductive mixtures, are described in the literature.[5,6]

Spear[2] tried to substitute LS by some less dangerous compounds but he found it too difficult to fulfil the required[7] parameters for CC primers without using LS as a part of the pyrotechnic mixture. Bentley[8] and Redman[9] were interested in decreasing the electrical sensitivity of CC systems for 20 mm aircraft ammo to fulfil 1 A/1 W requirements on electrical sensitivity. They found that with a

Table 1. *Pyrotechnic priming CC mixtures used in explosive ordnance.*

Ingredient	M 52 DEFA[a]		N 8 Igniter[b]	N 43 Primer[c]	M 52 A3B1[d]
	Conducting mix	Priming mix			
Lead styphnate	95.0 – 95.5	48	97	98.5	40 ± 2.5
Graphite	4.5 – 5.0	2	3	4.5	–
Carbon black	–	–	–	–	0.75 ± 0.25
Barium nitrate	–	12	–	–	44.25 ± 2.5
Potassium perchlorate	–	28	–	–	–
Calcium silicide	–	10	–	–	13.0 ± 2.5
Titanium	–	–	–	–	–
Arabic gum	–	–	–	–	1.0 ± 0.25
Styphnic acid	–	–	–	–	1.0 ± 0.25
Reference	Spear[2]	Spear[2]	Spear[2]	Spear[2]	Spear[2]

[a] "Double base" primer for 30 mm aircraft cannon ammunition. [b] An igniter for electrical fuse. [c] Part or a primer for 4.5 inch naval ammunition (used in Australian Ordnance). [d] Primer for 20 mm F/A-18 ammunition (used in Australian Ordnance).

suitable selection of components it is possible to significantly decrease electrical sensitivity, almost to fulfil the 1A/1W criteria.

Civilian use of CC systems is presented in several patent[10,11] applications. CC systems are particularly applied in primers for special purposes and sporting caseless ammunition and in car restraint systems.[12]

The aim of this work is to verify the possibility of manufacturing cheap CC fuseheads using dipping technology for pyrotechnic mixture loading. Also required is the application of recent technology and construction for industrial detonators without changes to existing technology. The application of such a technology requires addition of some suitable binder, which brings completely different properties compared to the standard CC primers loaded by pressing technology.

Experimental

Materials used

Rehydrated lead styphnate having an average particle size of 22 µm from standard production at Austin Detonator, Vsetin, CZ, was used for sample preparation. Electron micrographs of the LS used are presented in Figure 2.

Fusehead skeleton

A standard bridge wire skeleton, without bridge, type NN 1.2 mm was used for the production of test samples. All the wire skeletons used for experiments were taken from serial production at Austin Detonator. Figure 3 presents the dimensions of NN 1.2 mm skeleton.

Conducting admixtures

Natural finely milled purified graphite and conductive carbon black were used as a conductive admixture. Graphite was supplied by manufacturer Maziva Tyn, Ltd, CZ. Types marked CR2996 and CR12996 were chosen. Conductive carbon black was supplied by manufacturer Cabot CS, CZ. The type marked Vulcan XC72R was chosen. This is added to plastic materials to improve ESD safety. Some of the properties of carbon black are listed in Table 3.

Electron micrographs of conductive admixtures are presented in Figure 4. Some mechanical and physical properties of the graphite tested are

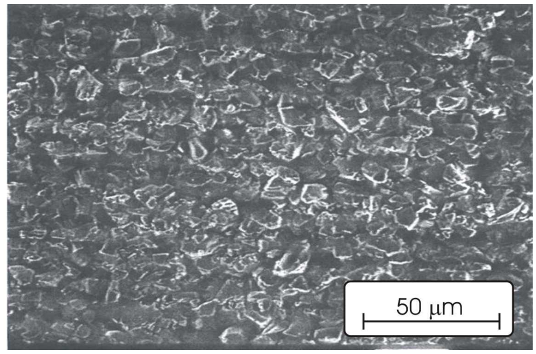

Figure 2. *Electron micrograph of LS used.*

presented in Table 2.

Binder

A 10% solution of Viton B in butyl acetate was used as a binder. Due to the time required for binder preparation (several weeks) samples from fusehead serial production at Austin Detonator were used. The quantity of binder added to a composition was the same as that used for standard bridge wire fuseheads.

Sample preparation

125 g of mixture with varying amounts of conducting admixture was always prepared for each sample. A list of the compositions prepared

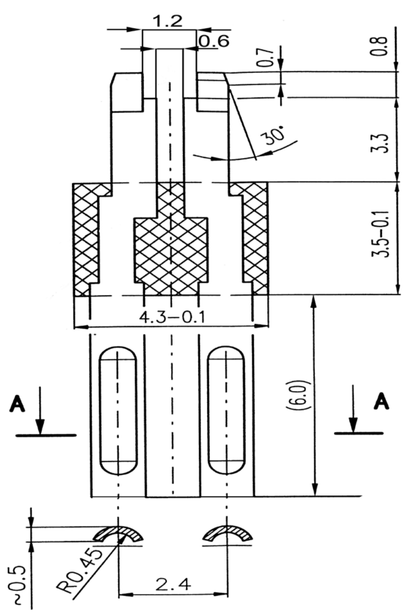

Figure 3. *Dimensions of wire skeletons used, type NN 1.2 mm.*

Table 2. *Graphite properties.*

	CR2996	CR12996
Carbon	99.7%	99.7%
Ash	0.3%	0.3%
Water	0.2%	0.2%
Particle size[a]	d_{50} 4.0 μm	d_{50} 8.0 μm
	d_{90} 8.0 μm	d_{90} 22.0 μm
Surface area[b]	13 m^2 g^{-1}	6 m^2 g^{-1}
Volume density	160 g l^{-1}	200 g l^{-1}

[a] Data from manufacturer's MSDS, laser analysis. [b] N_2 BET isotherm.

and tested and their abbreviations is presented in Table 4. The production of the sample compositions involved first adding the required amount of LS, then the conducting admixture and finally the solution of binder. Complete mixing was conducted behind protective armour until homogeneous color and consistency were achieved. The mixed composition was then passed through a brass sieve (0.056 mm mesh) and thinned using clear butyl acetate to produce a consistency suitable for dipping. Each composition sample was used prepare 600 pieces in frames subdivided into 200 sections. The dipping process was repeated 2–3 times until the desired fusehead size was achieved. The fuseheads were then finished by painting with three layers of protective enamel. Photographs of the final CC fuseheads are presented in Figure 5.

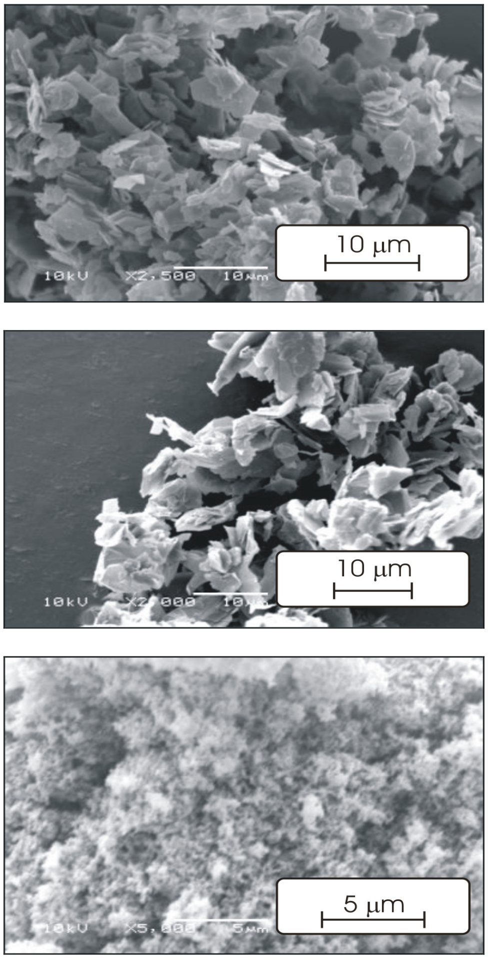

Figure 4. *Electron micrographs of conductive admixtures (Top: graphite CR2996. Middle: graphite CR12996. Bottom: Vulcan XC72R).*

Table 3. *Carbon black properties.*

	Particle size	Surface area	Solubility	Density
Vulcan XC72R	30 nm	254 m^2 g^{-1}	1.5%	100 g l^{-1}

Table 4. *List of pyrotechnic mixtures prepared and sample abbreviations.*

Abbreviation used	Content (%)			
	Graphite CR12996	Graphite CR2996	Carbon black	LS
CR12-5	5	–	–	95
CR12-10	10	–	–	90
CR2-5	–	5	–	95
CR2-10	–	10		90
S-1	–	–	1	99
S-2	–	–	2	98

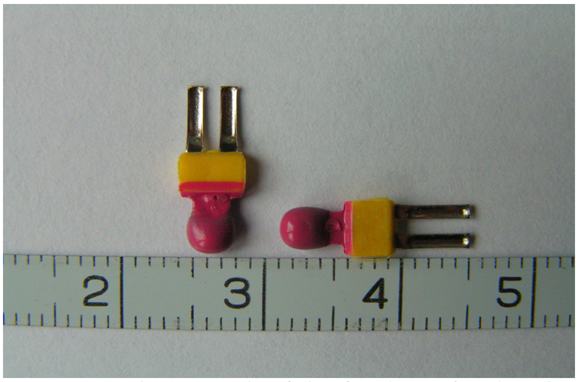

Figure 5. *Photograph of the final CC fuseheads on the NN wire skeletons (scale in cm).*

Determination of electrical resistance

Electrical resistance was measured by determining the volt–amp characteristics using a controlled DC power supply (Kikusui PAX 10A, 0–30 V) in the range 0–30 V. Current was measured using an ammeter (METEX 4270). Ten pieces from each composition sample were tested at the following voltage levels: 5, 10, 15, 20, 25, 30 V. Measurements made at 5 V were used as a comparison and the standard deviation calculated. The values of resistance measured at the different voltage levels are presented in Table 5. Each value is the average of 10 tests at the same voltage level.

Determination of firing energy

The comparative electrical sensitivity of the samples was measured by the amount of electrical energy consumed by the fusehead which was necessary for reliable ignition. For this purpose a capacitor firing unit consisting of a high voltage unit, a set of capacitors and safety and arming electronics was used. A precision current viewing resistor (CVR) was also used to measure current changes. This device also allows the simulation of the resistance of the leg wires – a nominal value of 5 Ω was used to simulate the influence of the firing circuit (leg wires, wire connection of wires, connecting terminals, etc.) A 20 µF capacitor was used in all these tests. The firing energy was calculated from the voltage drop recorded across a current viewing resistor, using one channel of a digital oscilloscope. Figure 6 shows a typical record of firing, where channel 3 presents the voltage change across the current viewing resistor and channel 2 shows the signal picked up by an explosion probe (described later) from the explosion of the detonator secondary charge. To make calculation easier, a simplification was used: typical current passing through the fusehead was taken to be rectangular in shape (see Figure 6). Then the firing energy, consumed by the fusehead is given by the following equation: $E = t_p \cdot I_0 \cdot U$, where t_p is the time during which current passes through the fusehead, I_0 is the magnitude of the

Table 5. *Electrical resistance in ohms of the fuseheads (calculated using their V–A characteristic data).*

	Voltage (V)						Std. Dev.[c] at 5 V
Sample	5	10	15	20	25	30	
CR2-5	2349	2207	2670	2975	3350	3589	234
CR2-10	103	172	258[a]	n/a	n/a	n/a	2.2
CR12-5	31 238	34 062	49 928	40 931	40 041	22 597	12 000
CR12-10	143	259	460	745[b]	n/a	n/a	8
S-1	10 080	9920	9732	7911	7886	7915	700
S-2	10 330	10 101	9888	9803	9811	9829	2200

Note: n/a means that all the samples tested under that condition initiated immediately after application of the testing voltage without change the measured current value. All values are presented in ohms; the standard deviation for level of 5 V was calculated from all values of resistance [a] 3/5 of the samples initiated immediately after a few seconds after the application of the test voltage. [b] 1/5 of the samples initiated immediately after a few seconds after the application of the test voltage. [c] The one-sigma standard deviations were calculated using the $n - 1$ method. This is an indication of the precision (reproducibility) of the timing of the event. Approximately 70% of the events occurred within plus or minus one standard deviation of the average.

current passing through and U is the initial value of the voltage across the capacitor before discharge. t_s is the reaction time of the whole system, i.e. the time from when delivery of energy is first delivered to the fusehead to when the secondary charge explodes. The meaning of the symbols is also evident from Figure 6.

Reaction time of detonators

The prepared fuseheads were mounted on a standard detonator aluminum body equipped with a primary and a secondary explosive charge. The detonators were fired using the capacitor firing machine described above and their reaction times and firing energy recorded. 15 detonators from each type of fusehead were tested. The detonators were fired using a 20 μF capacitor charged to 260 V. The detonation of the secondary charge was observed using an explosion probe placed around the secondary charge of detonator. The probe consists of several coils of an insulated copper wire, which connected to a 9 V battery via parallel 100 kΩ resistor. The complete probe was monitored using another channel of the digital oscilloscope. The explosion of the detonator is registered as a voltage drop, because then the wire loop of the probe is broken by the secondary charge explosion. A typical signal from the explosion probe is presented in Figure 6. Figure 7 presents a

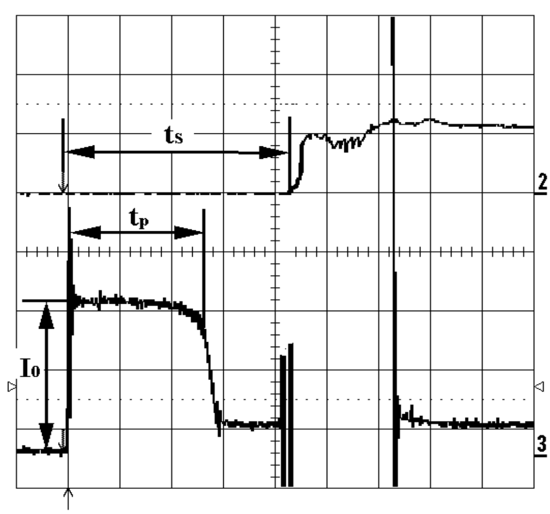

Figure 6. *Characteristic record of fusehead and detonator explosion captured using a digital oscilloscope. Channel 3 recorded the voltage on the current viewing resistor; channel 2 recorded the signal from the explosion probe.*

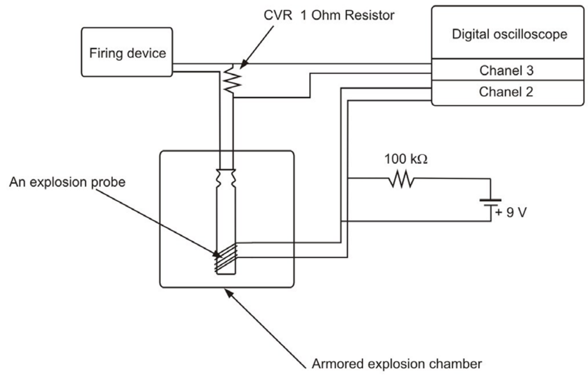

Figure 7. *The configuration of the equipment used for testing of the electrical sensitivity and reaction time.*

schematic of the measuring apparatus. Detonators were fired in the specially designed armored protection chamber allowing experimental work to be conducted safety. The chamber has its own system of ventilation and wire terminals for the probes and leg wires.

Results and Discussion

An overview of the measured electrical resistances at the 5 V level is presented in Table 5. The lowest resistance, 104 Ω, was achieved by the composition containing 10% of CR2996 graphite. Comparison with other data reveals that increasing the graphite above 10 % content does not bring any significant decrease of resistance in any composition. Those compositions containing 5% graphite exhibit a strong influence of the graphite particle size. Composition CR2-5 has a resistance several times higher than the composition containing 5% CR12996 (CR12-5). Compositions containing carbon black as the conductive admixture and Viton B as the binder are generally less sensitive on percentage of admixture content. This contrary to the findings of some authors[4] and is probably due to the binder added to the composition acting as an insulating layer between the conductive particles and so raising the electrical resistance of fuseheads. This is in agreement with the fact that similar compositions[3,4] which do not contain a binder with the same content with the same conductive admixture content have much lower resistances and are also more sensitive to amount of added binder. Samples made from the composition CR2-10 exhibited the best uniformity of resistance fluctuating about 2.1% around the

Table 6. *Results for the fusehead electrical sensitivity tests.*

Sample	Energy (mJ)
CR2-5	9.7
CR2-10	11.8
CR12-5	3.7
CR12-10	86.5
S-1	2.0
S-2	3.1

average. On the other hand the highest resistance fluctuations occurred in compositions with the same type of graphite, but with 5% content. This is probably caused by the higher degree of coating of the small graphite particles by binder. This could cause less good physical contact between the graphite particles reducing the number of conducting paths through the composition. The resistance of some samples was so high that ignition failure was caused. The resistance data also show a rapid increase of resistance value with applied voltage in graphite compositions with graphite content of about 29%. On the other hand the situation in compositions containing carbon black is completely different: increasing the applied voltage causes the resistance to decrease to around 10% of the initial value. These are clearly therefore differences in the conduction mechanisms between compositions that contain graphite and those that contain carbon black. This fact is confirmed by differences in the electrical sensitivity of compositions that contain graphite compared to those that contain carbon black, although on the basis of the energy consumed, carbon black compositions seem to be more sensitive.

Compositions containing 10% of graphite exploded in 60% of the trials conducted at 15 V. Above this level all samples made from CR2-10 composition initiated. This sensitivity could be explained by better contact between smaller particles of graphite thus leading to the formation of more "hot spots" where local overheating occurs when current passing through. These "hot spots" rapidly increase the chance of local overheating of lead styphnate particles leading to explosion/ignition of the complete fusehead.

Electrical sensitivity data are presented in Table 6. It can be clearly seen that the lowest sensitivity to electrical discharge of the compositions tested are those containing carbon black (S-1, S-2) with values 2.0 mJ and 3.1 mJ respectively. Comparing with other authors[3,4] the amount of carbon black addition does not have as great an effect as is usually claimed. On the other hand the amount of the graphite added rapidly changes the sensitivity especially of compositions with CR12996 graphite. Changing the CR12996 graphite from 5% to 10% causes the sensitivity to electrical energy to decrease by a factor of almost 24. On the other hand compositions containing finer grained graphite (CR2996) do not show such behavior. This highlights again the relationship between conducting admixture particle size and binder. The binder produces a very thin coating over the particles in the mixture decreasing the number of conducting paths created and raising the number of places with high resistance. This brings about an increase in the current flow through these places producing "hot spots" where lead styphnate could be initiated. This increase in the number "hot spots" in the composition brings about the higher sensitivity of the final fusehead to electrical energy. Data from the volt–amp experiments show compositions with the CR12996 graphite to be more resistant to this phenomenon.

The most interesting data were obtained from reaction time measurements. Generally detonators equipped with CC fuseheads have very short reaction times. It is generally known that the key factor for final promptness of a detonator (or any EED) is the speed of response of the fusehead to an electrical stimulus. The best response of the detonators examined was achieved with an S-2 fusehead, namely 113 µs. The best quality of response was obtained from CR2 compositions where the standard deviation in the response

Table 7. *Reaction times of detonators with CC fuseheads.*

Sample	Reaction Time (µs)	Std. Dev. (µs)
CR2-5	174	8
CR2-10	228	18
CR12-5	199	55
CR12-10	132	15
S-1	162	68
S-2	113	12

time was 4.6% (8 µs). Results from reaction time measurements are presented in Table 7.

Conclusions

Experiments have been completed which demonstrate the possibility of producing conductive composition fuseheads built on a standard NN 1.2 mm fusehead skeleton used for standard bridge wire fuseheads. It was found there is no need to significantly change the standard dipping technology used for CC fusehead manufacture. The results show a significant effect on the fusehead electrical properties of both particle size and origin of the conducting composition. By varying of these parameters and selecting a suitable conducting admixture it is possible to vary the fusehead properties over a wide range.

The application of conducting fuseheads to a standard detonator allows very short reaction times to be achieved compared to systems containing a standard bridge wire initiator. All the detonators tested had reaction times (the time from first initiation stimulus to explosion of the secondary charge) less than 1 ms without using any special firing conditions. CC systems bring about reaction at least ten times faster compared to standard hot bridge wires, but with very low manufacturing costs. The application of CC systems could be in devices where fast reaction times are required, e.g. seismic exploration, electronic firing systems or in applications where high precision simultaneous ignition is required, e.g. special firework displays or special pyrotechnic effects.

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