Research paper

Experimental investigation of mechanical sensitivity and noise level for different pyrotechnic flash compositions

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Abstract

The impact and friction sensitivity measurements of Potassium nitrate, Barium nitrate, Potassium perchlorate and Strontium nitrate based pyrotechnic flash compositions are reported. The flash compositions are classified according to the Andreiev–Beliaev classification of explosivity of substances based upon its impact sensitivity. It was found that potassium perchlorate and barium nitrate based compositions were high sensitive to impact in the range of 2 to 7.5J. The sensitivity to friction for potassium perchlorate based compositions was greater (up to 32N) compared to other flash compositions. Potassium nitrate based flash compositions were found to be best suited for Indian Fireworks manufacturing units as the noise level were within the prescribed norms of Indian Governmental Gazette notification on noise standards for firecrackers

Keywords : Fireworks, Impact sensitivity, Friction sensitivity, Flash composition, Noise level measurement,

1. Introduction

The manufacture of pyrotechnic mixtures involves different operations like grinding, sieving, mixing, filling, packing and transportation. During these operations, the chemical mixtures have the potential to experience mechanical stimuli (i.e. impact and friction) and this triggers an explosion that leads to a major accident. The sensitivity of a mixture to its explosion cannot be theoretically predicted as it depends on the reactive nature of the mixture components and the conditions employed during its preparation and handling. Though Material Safety Data Sheets (MSDS) of pure chemicals are readily available, no such data are available for mixtures[1]. Additionally, the mixture's composition varies from company to company for the same type of application[2].

Among all the fireworks compositions, flash and sound producing compositions are highly explosive, and will detonate if a sufficient quantity of powder is present in bulk form, even if unconfined[3)4)]. Commonly one of these components potassium chlorate/potassium perchlorate/barium nitrate/potassium nitrate is used as an oxidizer in a flash composition whereas sulphur is used as the igniter due to its lower melting point (119°C) and aluminum/magnesium/charcoal as the fuel.

As per the Indian Explosives Act, 1884, the use of chlorate and sulphur mixtures is prohibited due to its ease of ignition and sensitiveness to undergo explosive decompositions[5]. Alternate mixtures for the flash compositions such as those based on nitrate and perchlorate have been widely used in the fireworks industry. Nonetheless, accidents still occur.

In the past researchers[1)6)7)] have studied the thermal stability and mechanical sensitivity of sulphur/chlorate and potassium nitrate/sulphur/aluminum mixtures. However, a comprehensive study on mechanical sensitivity of various flash composition by varying its oxidizers and fuels has not yet been carried out. The present study has multiple objectives ; the first is the classification of the various flash compositions according to the Andreiev–Beliaev classification of explosivity of substances[8]. The other ob-

Table 1 Mechanical Sensitivity and Noise level measurement for potassium nitrate and barium nitrate based flash composition

Sample. No	Types of Flash Compositions	Flash Compositions Wt %	Impact Sensitivity (J)	Friction Sensitivity (N)	Noise Level (dB AI_{max})
1	Potassium Nitrate based	Al.....20 KNO_3.....50 S.....30	5.2974	324	114.4
2		Al.....50 KNO_3...50	17.658	Above 360	111.4
3		Mg....50 KNO_3...50	17.658	Above 360	No explosion (Fountain effect)
4		Charcoal...25 KNO_3...50 S...25	NO RESULT	Above 360	96.75
1	Barium Nitrate based	$Ba(NO_3)_2$..66 Al...25 S...9	3.1392	324	116
2		$Ba(NO_3)_2$..68 Al...23 S...9	3.924	252	114.1
3		$Ba(NO_3)_2$..57 Al...28 S...15	2.943	288	114.5
4		$Ba(NO_3)_2$..64 Al...20 S...16	3.1392	240	116.3
5		$Ba(NO_3)_2$..70 Al...10 S...20	3.924	216	No explosion (Rocket effect)

jectives are : to study and compare the impact and friction sensitivities of various flash compositions measured using a drop weight apparatus (an equipment similar to BAM fall hammer) and BAM friction tester respectively ; to study noise level for all compositions and arrive at ratios of ideal compositions based on optimal sensitivity and sound levels specified by legislation. .

2. Experimental

2.1 Materials

The chemicals used for the preparation of the flash compositions were obtained from fireworks manufacturing company situated in the southern state of Tamilnadu, India. The purity and assay of the chemicals were : Potassium nitrate − 91.6%, Barium nitrate − 92%, Potassium perchlorate − 93%, Strontium nitrate − 92% and Sulphur − 99.84% and Aluminum − 99.71%, Magnesium − 99% and Charcoal − 98%. The chemicals were passed through a 100 −mesh brass sieve. The shape of Aluminum and Magnesium particles was flake like. The samples were stored in an airtight container and kept away from light and moisture. The different flash compositions were taken from the standard references[9)–12)] and it is shown in the table 1.

2.2 Measurement of impact sensitivity

The impact sensitivity measurements of the flash compositions were carried out according to the procedure outlined in the United Nations (UN) Recommendations on the transport of dangerous goods[13)]. The design and principle of the equipment were similar to those of a drop fall hammer of BAM standards. The details of the equipment employed have been presented elsewhere[1)]. The impact sensitiveness was measured in terms of the Limiting Impact Energy (LIE). It is defined as the lowest impact energy at which the result "explosion" is obtained from at least one out of six trials and calculated using equation (1)

$$LIE = mgh \quad (1)$$

where

LIE − limiting impact energy in joules (J)
m − weight of the drop mass in kilograms (kg)
g − acceleration due to gravity (9.81 m/s^2)
h − fall height in meters (m)

2.3 Measurement of friction sensitivity

The friction sensitivity measurements of the flash compositions were carried out by BAM (friction tester) according to the procedure outlined in the United Nations (UN)

Table 2 Mechanical Sensitivity and Noise level measurement for potassium perchlorate and strontium nitrate based flash composition

Sample. No	Types of flash	Flash Compositions Wt %	Impact Sensitivity (J)	Friction Sensitivity (N)	Noise Level (dB AI_{max})
1	Potassium Perchlorate based	$KCLO_4$..64 Al...23 S..13	3.924	42	128.1
2		$KCLO_4$..53 Al...31 S...16	4.1202	56	127.7
3		$KClO_4$..50 Al...25 S...25	2.943	32	129.1
4		$KCLO_4$..50 Al...23 S...27	3.1392	36	127.2
5		$KCLO_4$..66 Al...34	5.1012	160	127.9
6		$KCLO_4$..70 Al...30	6.1202	120	128
7		$KCLO_4$..72 Al...28	7.848	60	128.8
1	Strontium Nitrate based	Al...70 $Sr(NO_3)_2$..30	3.924	Above 360	114.25

Recommendations on the transport of dangerous goods[14]. About 10 mm^3 (approximately 10 to 15 mg) of the sample was placed in the front and under the porcelain pin. The loading arm was loaded with the required weights and the switch operated. Care was taken so that sufficient material was ahead of the pin during friction when the plate moved. The friction sensitiveness was measured in terms of the *Limiting load*. Limiting load is defined as the lowest load at which the result "explosion" is obtained from at least one out of six trials.

2.4 Measurement of Sound Level

Sound levels of the flash composition reported in this study were measured using the sound level monitor, Model No. 824 obtained from M/s. Larson-Davis, USA. A test charge of the flash composition was made and the sound levels were measured according to the specification given in Government of India's gazette notification[15] for sound level measurement. The distance from the sample to the sound meter was 4m. The test charge (see Figure 3), was approximately 25 mm in length, composed of a three-tier paper board (thickness 1.5 mm). The arrangement was compacted clay at the bottom, about 1.6 g of flash composition in the middle, and compacted clay added to the top layer. A fuse (approximately 22 mm in length) was placed at the center of the test charge. All the test charges were ensured identical by its shape, size, density or compactness of chemical compositions and conditions by preparing under trained and skilled manpower. The average results from three replicate experiments with the test charge for noise level measurement (dB AI_{max}) of each sample are summarized in Table 1 and 2.

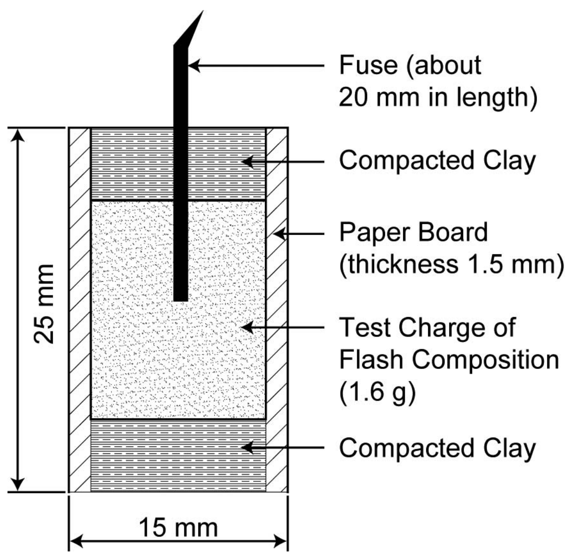

Fig. 1 Design of Test charge of Flash composition prepared for noise level measurement

3. Results and discussion

Table 1 shows the result of mechanical (impact and friction) sensitivity and noise level measurements of potassium nitrate and barium based flash composition. Whereas, the results of mechanical (impact and friction) sensitivity and noise level measurements of potassium perchlorate and strontium nitrate are tabulated as shown in Table 2

The test results assessed for impact and friction sensitivities on the basis of :

- *Whether an explosion occurs in any of up to six trials at a particular impact or friction sensitivity*
- *The lowest sensitivity at which at least one explosion occurs in six trials.*

In general, it was seen that all the flash compositions are sensitive to both impact and friction except black powder (mixture of charcoal, potassium nitrate, sulphur) based composition. The analysis of different flash composition has been discussed based upon its oxidizer in the mixture. The various oxidizers used in this study for flash composition are potassium nitrate, barium nitrate, potassium perchlorate, strontium nitrate.

3.1 Potassium nitrate based flash composition

Potassium nitrate based flash compositions have shown that the mixture was less sensitive to both impact and friction. But combination of ternary mixtures (aluminium, potassium nitrate and sulphur) showed higher impact sensitivity in the order of 5.3 J and friction sensitivity in the order of 324 N compared to other potassium nitrate based binary flash compositions.

The results also showed that the flash compositions consisting of potassium nitrate / aluminum and potassium nitrate / magnesium did not show any significant variations in both impact and friction. From the close observation of results in Tables 1, it can be seen that flash composition having sulphur content showed higher impact sensitivity as well as friction sensitivity. Hence, sulphur concentration in a mixture played a major role in increasing the sensitivity of potassium nitrate based flash compositions. Since the impact sensitivity of potassium nitrate based flash compositions fell in the range of 5.3 J to 17.6 J, the mixture could be classified as class III according to Andreive Bilaive classifications[8].

In the noise level measurement, inclusion of sulphur content in potassium nitrate based flash compositions increased the noise level. Surprisingly, it was seen that without sulphur content in the mixture, the flash composition has exploded well with a noise level of 114 dB. In potassium nitrate based flash composition, on replacing the aluminum fuel by magnesium fuel, it did not explode. During cracking of test charge, It was observed that addition of magnesium with potassium nitrate only has the effect of fountains or rockets rather explosion. This might be due to high burning rate of magnesium. The black powder consisting of (charcoal, Potassium nitrate and sulphur) has exploded with less noise.

3.2 Barium nitrate based flash composition

The results in Table 1 showed that the barium nitrate based flash compositions were highly sensitive to impact and moderately sensitive to friction. The impact sensitivity of barium nitrate based flash composition fell in the range of 2.9 J to 3.9 J which could be classified as class IV according to Andreiev−Beliave classifications[8]. Friction sensitivity of barium nitrate based flash compositions fell in the range of 216 N to 324 N of limiting load.

The close observation of results showed that with the increase in sulphur content from 9% to 16% in the barium nitrate based flash composition increased the impact sensitivity. Beyond sulphur content of 16%, the flash composition became less sensitive to impact. The less concentration of sulphur in the mixtures showed that flash compositions were more sensitive to friction. In general, aluminum concentration in the flash compositions showed a marked influence on the impact sensitivity.

All the barium nitrate based flash compositions has exploded well with a noise level of 115 dB except the flash composition consisting of barium nitrate−70%, aluminum−10%, sulphur−20%. This was due to the fact that the oxidizer played a major role in deciding the cracking nature of the test charge. When the barium nitrate content was increased beyond 68% in the flash compositions, the mixture became equivalent to the rocket effect. Surprisingly it did not explode. (refer table 2)

3.3 Potassium perchlorate based flash Composition

The results showed that potassium perchlorate based flash compositions were highly sensitive to both impact and friction. The impact sensitivity of potassium perchlorate based flash composition fell in the range of 2.9 J to 7.8 J. The friction sensitivity of potassium perchlorate based flash composition fell in the range of 32 N to 160 N of limiting load.

The close observation of results in Tables 2 showed that the ternary mixtures consisting of potassium perchlorate, sulphur and aluminum were highly sensitive to both impact and friction compared to other binary flash compositions. Hence, it is seen that the sulphur in a mixture played a major role in increasing the sensitivity of potassium perchlorate based flash compositions. According to Andreiev −Beliave classifications[8] based on the impact sensitivity, all the binary potassium perchlorate based flash compositions could be classified as class III explosives whereas ternary potassium perchlorate based flash composition could be grouped as class IV explosives.

Table 2 showed that the noise level measurement of potassium perchlorate based flash compositions produced higher decibel level which is more than 125 dB (AI_{max}) prescribed by Government of India's Gazette notification noise standards for firecrackers G.S.R.682 (E)[15].

3.4 Strontium nitrate based flash composition

The results showed that strontium nitrate based flash compositions are highly sensitive to impact and less sensitive to friction. The impact sensitivity of strontium nitrate based flash composition is 3.9 J.

The noise level of strontium nitrate based flash compositions has showed the same effect as that of Potassium nitrate based flash compositions in decibel.

4. Conclusion

The results showed that the potassium nitrate based flash compositions were less sensitive to both impact and friction compared to other flash compositions. The study showed that both barium nitrate and potassium perchlorate based compositions were high sensitive to impact in the range of 2 to 7.5 J. However, it is found that the sensitivity to friction for potassium perchlorate based compositions was greater (up to 32 N) compared to other flash compositions. The noise level measurements showed that the potassium perchlorate based firecracker exceeded the prescribed norms of ***Indian Governmental Gazette notification on noise standards for firecrackers G.S.R. 682(E) of 125 dB*** (AI_{max}). It was revealed that the potassium nitrate based flash compositions are best suited for the Indian fireworks manufacturing units as it has comparatively showed adequate noise level with less sensitive to impact and friction.

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