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Development and Study of High Energy Igniter/Booster Pyrotechnic Compositions for Impulse Cartridges

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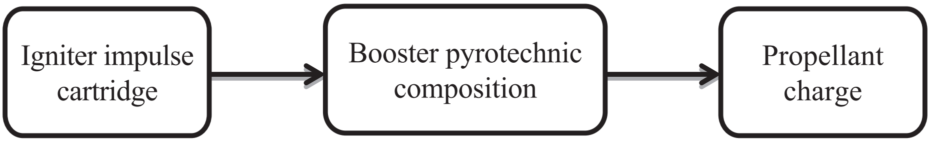
Abstract: In order to suitably initiate an impulse cartridge and to get the desired peak pressure, high energy igniter and booster pyrotechnic compositions may be required. Studies were undertaken to develop different types of high energy igniter and booster pyrotechnic compositions comprising B/KNO_3, $Zr/KClO_4$ and $Pb(SCN)_2/KClO_3$ as igniter compositions, and $B/Mg/KClO_4/Bi_2O_3$ and $B/Mg/KClO_4$ as booster compositions. Different ratios of fuels and oxidizers were studied in order to determine the best igniter and booster compositions. The measurement of the calorific values for the igniter and the booster compositions, along with safety tests of the igniter compositions, were performed. The pattern of calorific values observed for the igniter and booster compositions under study were $B/KNO_3 > Zr/KClO_4 > Pb(SCN)_2/KClO_3$ and $B/Mg/KClO_4 > B/Mg/KClO_4/Bi_2O_3$, respectively. The newly-developed high energy igniter compositions passed all of the safety tests. Both igniter and booster compositions were also subjected to functional tests in an impulse cartridge. The functional tests were intended for the determination of peak pressure and time to peak pressure. These high energy igniter and booster compositions increased the peak pressure by 8.3% and reduced the time to peak pressure by 14.3% for an impulse cartridge in a closed chamber of volume 230 cm^3. The consequence of this research work is that the best combination of igniter and booster compositions in terms of safety, calorific values and cartridge functionality are $Zr/KClO_4$ (40/60) and $B/Mg/KClO_4$ (30/10/60), respectively.

Keywords: calorific value, max no fire current, stray voltage, static discharge, peak pressure

1 Introduction

Pyrotechnics are types of energetic materials which produce special effects when suitably initiated. These consist of fuel, oxidants and binders. The nature of these ingredients has an effect on the ignitibility of the igniter, booster and delay pyrotechnic compositions. Pyrotechnic compositions are used for military as well as for civilian purposes. The most important applications of pyrotechnic compositions are their use in impulse cartridges. Impulse cartridges are Electro Explosive Devices (EEDs) consisting of a pyrotechnic igniter and booster compositions followed by a propellant charge. These EEDs use electrical energy as the initial stimulus to initiate the igniter composition for subsequent initiation of the pyrotechnic train. Impulse cartridges are used for the release of weapons from Military Aircraft. The pyrotechnic train for an impulse cartridge is:



The electrical igniter of an impulse cartridge consists of an igniter composition, resistive wire, igniter body, pole piece and washer. The igniter composition is initiated through electrical or mechanical stimulus. The resistive wire ignites the igniter composition by the joule effect when an electric current is passed. The performance of a high energy pyrotechnic composition depends upon:

- the ability to ignite the material using an external ignition source,
- the ability of the composition, once ignited, to sustain propagation in the remaining composition.

The igniter composition of an impulse cartridge should not be very insensitive otherwise it would be very difficult to initiate by the required stimulus. On the other hand, the igniter composition should also not be too sensitive to accidental initiation when subjected to electrical energy below a predetermined level. Therefore, the igniter composition must qualify the required safety tests including maximum no fire current, static discharge and stray voltage, to ensure safe handling, transportation and storage, along with a reduction of hazard during its life cycle [1-5]. The energy of the igniter composition is generally not enough to reliably initiate the main propellant charge, therefore a booster pyrotechnic composition is incorporated between the igniter and the main propellant charge to enhance the output pressure [6, 7]. The booster pyrotechnic composition should be sensitive enough to be initiated by the igniter composition and must have a high heat output to easily initiate the main propellant charge in the impulse cartridge to produce the required pressure. The calorific value or heat of reaction is an important parameter of igniter/booster pyrotechnic compositions and propellant charges. It is the amount of energy produced per unit charge (J/g). The calorific value is determined experimentally using a calorimeter. Calorific values for different types of pyrotechnic compositions have been reported in the literature [8-11]. Different types of igniter compositions, such as B/KNO_3, Zr/$KClO_4$, Zr/$BaCrO_4$, and Fe_2O_3/Al, are commonly used in igniters [12-17].

A thorough literature survey was conducted, but little data was found on igniter and booster pyrotechnic compositions for impulse cartridges and finding the best igniter and booster composition is still an unresolved problem. This experimental work was focused on the development of igniter and booster pyrotechnic compositions employed in impulse cartridges, to enhance their performance in terms of peak pressure for military use. These compositions were required to have a high heat output to increase the pressure of the impulse cartridge inside the closed firing chamber. Additionally, the igniter composition was also required to pass the required safety tests, including max no fire current (1 watt/1 A current for 5 min), stray voltage and static discharge as applicable in Military Standards.

2 Materials and Methods

2.1 Characteristics of the materials used

High purity Analytical grade fuels and oxidizers (Fluka/Sigma Aldrich) and commercial grade Fish Glue and Nitrocellulose Lacquer as additives were used during this work. The purity of these chemicals was 97-99%. The fuels and oxidizers used were fine powders. All of these fuels and oxidizers were passed through a 325 mesh sieve to obtain a final particle size of ≤ 44 µm.

2.2 Compositions preparation

2.2.1 Igniter and booster pyrotechnic compositions (without binder)

The moisture was removed from both fuels and oxidizers by drying these ingredients in an oven at 80 °C for 2 h. The chemicals were weighed according to the required percentages and then the ingredients were mixed in a (3-D) automatic Tumbler Mixing Machine. From the already mixed composition small batches of 5 g each were further processed by mixing the chemicals in a mortar and pestle in a specially designed fuming hood for 30 min in order to further homogenize the compositions. Three different types of igniter mixtures, A = B/KNO_3, B = $Zr/KClO_4$, and C = $Pb(SCN)_2/KClO_3$, with the fuel content being varied from 10% to 90%, were prepared. These igniter compositions were slurried in a nitrocellulose dipping grade lacquer in a 2:1 ratio. The slurry was then pasted onto the bridge wire of the igniters.

2.2.2 Booster pyrotechnic composition (with binder)

In order to remove the moisture both fuels and oxidizers were dried in a heating oven at 80 °C for 2 h. The chemicals were weighed according to the required percentages and then the ingredients were mixed in a (3-D) automatic Tumbler Mixing Machine. From the already mixed composition small batches of 5 g each were further processed by mixing the chemicals in a mortar and pestle in a specially designed fuming hood for 30 min in order to further homogenize the compositions. A binder solution of 4% fish glue was prepared in distilled water and this solution was mixed with the composition. A homogenous paste was prepared by using a spatula in an agate container. The paste composition was semi-dried in a drying oven at 80 °C. To avoid the formation of lumps, the semi-dried composition was carefully broken up with a spatula in an agate container. The composition was sieved gently through a 50 mesh sieve and retained on a 150 mesh sieve to obtain grain sizes of 106-297 μm. A Haver test shaker EML 200-89 digital was used for the preparation of grains of the required particle size [18]. The grains were dried for 4 h at 80 °C to remove water/moisture. The finished composition was stored in a special container and placed in a desiccator for 24 h to stabilize the composition.

2.3 Calorimetric measurements

An oxygen bomb calorimeter Parr 6200 with oxygen bomb 1108 was used in this work for the measurement of the calorific value of different igniter and booster pyrotechnic compositions. No oxygen was required for combustion because a pyrotechnic composition contains its own oxygen. The sample size was kept to ~0.5 g for each test.

2.4 Safety tests

Safety and reliability are the two most important parameters of any explosive device. The igniter of the impulse cartridge must be safe and reliable to produce the required results. The safety of an impulse cartridge is ensured by the design of the igniter and by preparing the igniter composition to qualify all the required safety tests in order to ensure safe operation, handling, transportation and storage as per the requirements of the applicable Military Standard.

2.4.1 Maximum no fire current test

This is a laboratory test for functional reliability, handling and tactical safety. Fifteen igniters were manufactured for this test, of which five igniters were pasted with each of the igniter compositions A = B/KNO_3, B = $Zr/KClO_4$ and C = $Pb(SCN)_2/KClO_3$, respectively. These igniters were then subjected to not less than 1 watt/1 A current for five minute to qualify the requirement of the applicable MIL-Standard [19]. The igniter should not fire during this test. A calibrated power supply was used for the measurement of the maximum no fire current test.

2.4.2 Static Discharge test

This is a laboratory safety and reliability test, simulating handling and transportation conditions. Fifteen igniters were manufactured for this test, of which five igniters were pasted with each of the igniter compositions, A = B/KNO_3, B = $Zr/KClO_4$ and C = $Pb(SCN)_2/KClO_3$, respectively. These igniters were subjected to 25000 V simulated human electrostatic discharge to qualify the requirement of the applicable MIL-Standard [19]. The igniter should not fire during this test. A static discharge tester ESD 300 System of EMC PARTNER was used for the purpose.

2.4.3 Stray Voltage test

This is a safety test in which the initiator shall be capable of withstanding the effects of a stray voltage environment without pre-igniting. As for the other tests a total of fifteen igniters were manufactured, of which five igniters were pasted with each of the igniter compositions, A = B/KNO_3, B = $Zr/KClO_4$ and C = $Pb(SCN)_2/KClO_3$, respectively. These igniters were subjected to 2000 pulses of direct current. Each pulse was of 300 ms duration and at a pulse rate was 2 pulses per second. Each pulse had a minimum amplitude of 100 ±5 mA to qualify the requirement of the applicable MIL-Standard [19]. A stray voltage tester of Thurlby Thunder Instrument Part No. TG 550 was used for the stray voltage tests.

2.5 Manufacture of an igniter for an impulse cartridge

The igniter is the main part of an impulse cartridge. The igniter consisted of a hot bridge wire, an igniter mixture pasted onto the bridge wire and mechanical components including an igniter body pole piece, washer and insulating cup.

The igniter was manufactured by assembling the mechanical parts followed by spot welding/soldering of the hot bridge wire onto the pole piece of the igniter. The prepared paste of the igniter composition was slurried in nitrocellulose dipping grade, in a 2:1 weight ratio. The paste of the igniter composition was then applied to the bridge wire of the igniter. It was then dried at 80 °C for 2 h. The specifications and a schematic diagram of the igniter are presented in Table 1 and Figure 1, respectively.

Table 1. Specification of the igniter for the impulse cartridge

Description	Specification
Bridge wire material (Nickel/Chromium)	80/20%
Wire diameter	0.046 mm
Wire length	4.0 mm
Resistance of wire per mm	0.097 Ω
Length to diameter ratio of bridge wire	87
Distance between pots	4.0 mm
Igniter mixture blended in NC lacquer	2:1
B/KNO_3	30% Boron
$Zr/KClO_4$	60% Zirconium
$Pb(SCN)_2/KClO_3$	40% $Pb(SCN)_2$
Mechanical components	01 set

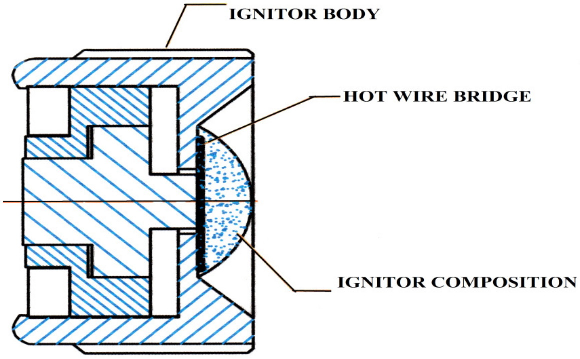


Figure 1. Schematic diagram of the igniter of the impulse cartridge

2.6 Cartridge assembly and functionality tests in a closed chamber

The steps followed for the manufacture of the impulse cartridges were: assembly of the igniter in the main cartridge body, filling of the booster composition in the cartridge body, filling of the main propellant charge and crimping of the impulse cartridge.

The peak pressure and time to peak pressure of the propellant cartridges was recorded in a closed bomb chamber [20]. The selection of the volume of the closed chamber for peak pressure and time to peak pressure measurements depends on the specific application. In this research a closed chamber of volume

230 cm^3 was used during these functionality tests. A pressure transducer of 250 bar, pressure calibrator and PICO software of the Kistler Company were used for the measurement of these two parameters. A schematic diagram for the measurement of peak pressure and time to peak pressure is shown in Figure 2.

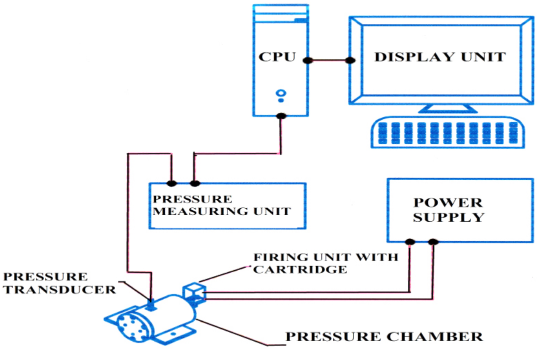


Figure 2. Schematic drawing of the experimental arrangement

3 Results and Discussion

3.1 Calorimetric measurement of the igniter compositions

3.1.1 B/KNO_3 igniter mixture-A

Table 2. Exothermicity measurements for a range of B/KNO_3 igniter mixtures

Test #	Boron [%]	KNO_3 [%]	Mean cal. value [J/g]
1	10	90	3144
2	17	83	6062
3	20	80	6389
4	25	75	7377
5	30	70	7549
6	40	60	7231
7	50	50	7080
8	60	40	6879
9	70	30	5711
10	80	20	4024
11	90	10	NR*

*NR means not recorded and ignition not observed

The calorific values of B/KNO_3 mixture are shown in Table 2 and Figure 3. These results show that the calorific values of this igniter mixture increased with increasing boron content until the maximum calorific value of 7549 J/g was recorded at 30% boron − almost all of the fuel reacted with the oxidant. The calorific value then decreased on further increase in boron content, until a misfire occurred in the calorimeter at 90% boron because the sensitivity of the composition was reduced at this ratio and the energy produced by the hot resistive wire was insufficient to ignite this mixture. A minimum calorific value of 3144 J/g was recorded at 10% boron.

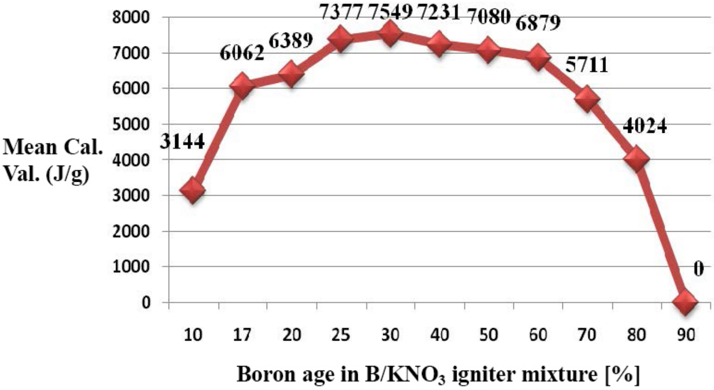


Figure 3. Plot of exothermicity against boron content for a range of B/KNO_3 igniter mixtures

3.1.2 Zr/$KClO_4$ igniter mixture-B

Potassium perchlorate is one of the important oxidizers in pyrotechnic formulations. It decomposes exothermically, as compared to other oxidizers. Zirconium fuel is a powerful reducing agent and reacts with an oxidizer at high temperature to release enough heat to ignite booster pyrotechnic mixtures. The reaction of zirconium and potassium perchlorate is a very fast reaction. The reaction of this fuel and oxidizer is given below.

$$2\,Zr + KClO_4 = 2\,ZrO_2 + KCl$$

The experimental results for the calorific values of Zr/$KClO_4$ mixtures are presented in Table 3 and Figure 4. These results revealed that the calorific value of this igniter composition increases with increasing zirconium content and a maximum value of 6125 J/g was observed at 60% zirconium − almost all of the fuel reacted with the oxidant. Further increase in zirconium content decreased the calorific value. At 10% zirconium content the igniter mixture failed to ignite because the energy produced by the resistive wire was not enough to ignite this mixture. A minimum value of 2654 J/g was recorded at 20% zirconium. An almost identical result (6061 J/g) was reported by Jinn-Shing Lee at 60% zirconium [21]. The safety tests reported in the literature were conducted using a Pt/It 80/20 alloy hot bridge wire. In the present work, the same tests for the Zr/$KClO_4$ igniter composition were conducted using a 80/20% nickel/chromium alloy hot bridge wire, in order to qualify the safety tests of the applicable Military Standard. Both results are in fair agreement.

Table 3. Exothermicity measurements for a range of Zr/$KClO_4$ igniter mixtures

Test #	Zirconium [%]	$KClO_4$ [%]	Mean cal. value [J/g]
1	10	90	NR*
2	20	80	2654
3	30	70	2868
4	40	60	4392
5	50	50	4919
6	60	40	6125
7	70	30	5782
8	80	20	4513
9	90	10	2922

*NR means not recorded and ignition not observed

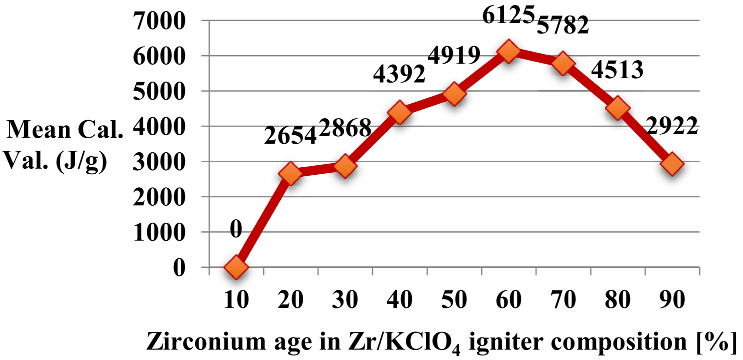


Figure 4. Plot of the exothermicity against zirconium content for a range of Zr/$KClO_4$ igniter mixtures

3.1.3 $Pb(SCN)_2/KClO_3$ igniter mixture-C

The results of the calorific values of the $Pb(SCN)_2/KClO_3$ igniter mixtures are presented in Table 4 and Figure 5. Different ratios (10~90% fuel) for these igniter compositions were tested to determine their calorific values. The value increased with increases in lead thiocyanate content. The maximum calorific value of 4333 J/g was recorded at 40% lead thiocyanate. The calorific value then decreased with further increases in lead thiocyanate content. A minimum calorific value of 1030 J/g was recorded at 30% fuel. The composition misfired at 10%, 20% and 90% lead thiocyanate because the sensitivity of these compositions was reduced at these ratios and the energy produced by the resistive wire was insufficient to ignite this mixture.

Table 4. Exothermicity measurements for a range of $Pb(SCN)_2/KClO_3$ igniter mixtures

Test #	$Pb(SCN)_2$ [%]	$KClO_3$ [%]	Mean cal. value [J/g]
1	10	90	NR*
2	20	80	NR*
3	30	70	1030
4	40	60	4333
5	50	50	2935
6	60	40	2579
7	70	30	2206
8	80	20	2039
9	90	10	NR*

*NR means not recorded and ignition not observed

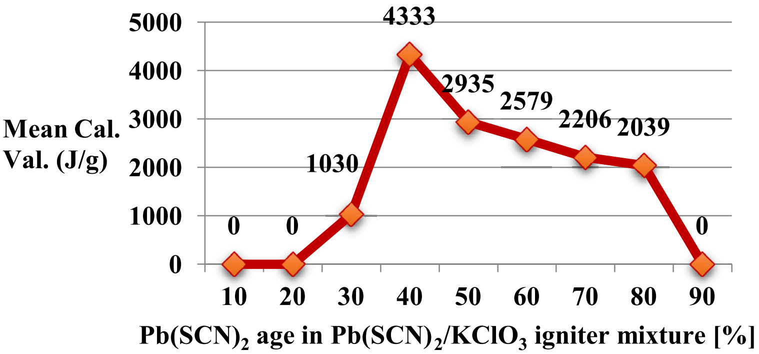


Figure 5. Plot of exothermicity against $Pb(SCN)_2$ content for a range of $Pb(SCN)_2/KClO_3$ igniter mixtures

3.2 Safety Tests Results

3.2.1 Maximum no fire current test

None of the igniters fired and all of the igniters passed this test when subjected to 1 watt/1 A, a direct current of not less than one ampere supplying a minimum of one watt applied to the bridge circuit for a period of at least five minutes. The results are shown in Table 5.

3.2.2 Static discharge test

None of the igniters fired and all of the igniters passed this test when subjected to the requirements of a 500 ±5% pF capacitor charged to 25000 ±500 V and 500 ±5% Ω resistors connected in a 5 μH total inductance series circuit between pairs of pins. The results are shown in Table 5.

3.2.3 Stray voltage test

None of the igniters fired and all of the igniters passed this test when subjected to 2000 pulses of direct current. Each pulse was of 300 ms duration and the pulse rate was 2 pulses per second. Each pulse had a minimum amplitude of 100 ±5 mA. The results of this test are shown in Table 5.

The results in Table 5 show that the 40% $Pb(SCN)_2/KClO_3$ mixture is the most sensitive whereas 30% B/KNO_3 is the least sensitive to electrical stimuli of the three compositions. All of the igniter compositions are suggested as reliable igniter compositions for qualifying the above tests, 1 W/1 A direct current for not less than 5 min, static discharge and stray voltage, for impulse cartridges. These compositions were investigated by using (nickel/chromium) = 80/20%, with diameter 0.046 mm and length 4.0 mm, as a hot wire bridge. If the type or diameter of the bridge wire were changed, then re-qualification would be required, because the sensitivity of the igniter composition changes with a change in type and diameter of the hot bridge wire. When the diameter of a bridge wire is decreased, the resistances of the bridge wire increases because the resistance is inversely proportional to the diameter of the wire. When the resistance of the bridge wire is increased, the composition becomes more sensitive to electric currant and vice versa. The larger the resistance of the hot bridge wire, the greater is the heat dissipated from the bridge wire and hence the composition becomes more sensitive. Further investigation would be required for the qualification of the safety tests of these igniter compositions if the type or diameter of the bridge wire were changed.

Table 5. Comparison of the different results for the ignition compositions

Mixture	Description	Calorific value [J/g]	Safe current [A]	Stray voltage	Static discharge	Firing current [A] at 1 VDC
A	30% B/KNO_3	7549	1 W/1 A	passed	passed	1.7~1.8
B	60% $Zr/KClO_4$	6125	1 W/1 A	passed	passed	1.4~1.5
C	40% $Pb(SCN)_2$ / $KClO_3$	4333	1 W/1 A	passed	passed	1.2~1.3

3.3 Calorimetric measurement of the booster compositions

3.3.1 Existing booster composition

A booster pyrotechnic composition with weight percentages of $B/Mg/KClO_4/Bi_2O_3/BaCrO_4$ = 5:17:31:7:40 was chosen as the original/reference booster composition. Three samples of this composition were tested for their calorific value. The calorific value of this original/reference booster composition was 6100 J/g, as shown in Table 6.

Table 6. Calorific value of the original booster pyrotechnic composition

Formulation	Binder	Grain size [µm]	Mean cal. value [J/g]
$B/Mg/KClO_4/Bi_2O_3/BaCrO_4$ = 5:17:31:7:40	Fish glue 4 wt.% additional	106~297	6100

3.3.2 Newly prepared high energy booster composition (New-1)

Two fuels and two oxidizers were used during preparation of this mixture. Different ratios of the ingredients, B, Mg, $KClO_4$, Bi_2O_3 and fish glue were tested, and the best result was obtained with $B/Mg/KClO_4/Bi_2O_3$ = 5:17:71:7 with 4% additional fish glue as binder. The results are shown in Table 7. The purpose of adding fish glue as a binder was to protect the composition from environmental effects, especially humidity, because most of the pyrotechnic compositions are affected by the humidity. Additionally, the binder also reduces the sensitivity of the composition to avoid accidental initiation during the manufacturing process, especially during grain preparation when the composition is passed through sieves. The maximum mean calorific value recorded for a series of booster compositions was 6770 J/g. This result reveals that the calorific value of the newly prepared booster pyrotechnic composition (New-1) is almost 11% higher than the original/reference booster pyrotechnic composition.

Table 7. Calorific value of the newly prepared booster pyrotechnic composition (New-1)

Formulation	Binder [wt.%]	Particle size [μm]	Mean cal. value [J/g]
$B/Mg/KClO_4/Bi_2O_3$ = 5:17:71:7	Fish glue 4 wt.% additional	106~297	6770

3.3.3 Newly prepared high energy booster composition (New-2)

A total of 16 different types of booster compositions were investigated as shown in Table 8. Mostly, these compositions consisted of two fuels and one oxidizer. Different ratios of the ingredients, B, Mg, $KClO_4$ and fish glue were tested. The results presented in Table 8 show that the initial five mixtures were not ignited by the hot bridge wire of the bomb calorimeter, because the compositions with these ratios were not sufficiently sensitive to be initiated. In other words, the compositions containing magnesium, potassium perchlorate and less than 5% boron were not initiated by the heat liberated by the hot bridge wire of the calorimeter. At ≥5% boron, the mixture was initiated by the hot bridge wire of the bomb calorimeter. The results in Table 8 also show that the calorific value significantly increased when the potassium perchlorate content was reduced to 60%. At this percentage of the oxidizer, the calorific value varied from 9902 J/g to 10362 J/g on changing the ratios of the two fuels boron and magnesium.

The results in Table 9 give a summary of the booster compositions (New-2). There is no significant difference in the calorific values of the ingredients at these ratios. However, the maximum calorific value recorded for the newly prepared booster composition $B/KClO_4$ = 40/60 was 10362 J/g, without binder and for B/Mg/KClO4 = 30:10:60 was 10190 J/g with 4% binder. This means that the calorific value of the newly prepared booster pyrotechnic composition (New-2) is almost 70% and 67% higher than the original/reference booster pyrotechnic composition, without and with 4% binder, respectively.

Table 8. B/Mg/$KClO_4$ booster pyrotechnic compositions (New-2)

Test #	B [%]	Mg [%]	$KClO_4$ [%]	Mean cal. value [J/g]	Binder/grain size
1	0	15	85	misfired	without binder
2	1	14	85	misfired	without binder
3	2	14	84	misfired	without binder
4	3	15	82	misfired	without binder
5	4	15	81	misfired	without binder
6	5	15	80	4279	without binder
7	5	15	80	6360	106~297 μm
8	0	40	60	misfired	without binder
9	5	35	60	9952	without binder
10	10	30	60	9998	without binder
12	20	20	60	9902	without binder
13	30	10	60	10161	without binder
14	30	10	60	10190	106~297 μm
15	40	0	60	10362	without binder
16	40	0	60	10048	106~297 μm

Table 9. Summary of calorific value of the newly prepared booster compositions (New-2)

S #	Formulation	Mean calorific value [J/g]	Binder/grain size
1	B/Mg/$KClO_4$ = 5:35:60	9952	without binder
2	B/Mg/$KClO_4$ = 10:30:60	9998	without binder
3	B/Mg/$KClO_4$ = 20:20:60	9902	without binder
4	B/Mg/$KClO_4$ = 30:10:60	10101	without binder
5	B/Mg/$KClO_4$ = 30:10:60	10190	106~297 μm
6	B/$KClO_4$ = 40:60	10362	without binder
7	B/$KClO_4$ = 40:60	10048	106~297 μm

3.4 Selection of the Igniter and Booster Compositions for the Impulse Cartridge

Zr/$KClO_4$ = 60:40 was selected as the final igniter composition. Although this composition has a calorific value less than that of the B/KNO_3 mixture, this composition has a bulk density greater than that of the B/KNO_3 mixture. The average weight of the Zr/$KClO_4$ mixture accumulated in the total available volume of the igniter body was 113 mg, whereas the average weights of igniter compositions A = B/KNO_3 and C = $Pb(SCN)_2$/$KClO_3$ accumulated in the total available volume of the igniter body were 123 mg and 84 mg, respectively. Therefore the total resultant heat output of the Zr/$KClO_4$ = 60:40 igniter composition was 8.4% and 23% higher than the total heat output of the B/KNO_3 = 30:60 and $Pb(SCN)_2/KClO_3$ = 40:60 igniter compositions, respectively. The charge weights, calorific values and calculated total heat outputs of these igniter compositions are listed in Table 10.

Table 10. Comparisons of all three igniter compositions

Igniter composition	Mass in primer body [mg]	Calorific value [J/g]	Total heat output [J]
30% B/KNO_3	84	7549	634
60% Zr/$KClO_4$	113	6125	692
40% $Pb(SCN)_2/KClO_3$	123	4333	533

The quantity of booster pyrotechnic composition in the impulse cartridge was kept fixed during each of the tests for the measurement of peak pressure and time to peak pressure. Of the seven different types of booster pyrotechnic compositions tested, B/Mg/$KClO_4$ = 30:10:60 wt.% was selected as the final booster composition. The grain size and calorific value of this composition were 106~297 μm and 10190 J/g, respectively, as shown in Table 11. However the calorific value of this composition is slightly smaller than 10362 J/g (B/$KClO_4$ = 40:60). The reason for the selection of this composition as the final one was because it contains a binder and the binder protects the fuel and oxidizer from environment effects such as humidity. Additionally the binder also increased the cohesion between particles of fuels and oxidizers to protect them from being segregated due to their difference in density. The grains also provided ease of loading of the composition in the cartridge body.

Table 11. Final selected igniter and booster pyrotechnic compositions

Type of composition	Ingredients and wt.% of composition	Mean calorific value [J/g]	Binder/grain size
Igniter	Zr/$KClO_4$ = 60:40	6125	without grain
Booster	B/Mg/$KClO_4$ = 30:10:60	10190	106~297 μm

3.5 Functional tests results

The functional test results (peak pressure and time to peak pressure) are shown in Table 12 and in Figures 6 and 7. These results show that the newly prepared igniter composition Zr/$KClO_4$ = 60:40 and booster composition B/Mg/$KClO_4$/Bi_2O_3 =

5:17:71:7 increased the peak pressure of the impulse cartridge by 6.2% in a closed chamber of volume 230 cm^3. Similarly, the same igniter composition and the booster composition B/Mg/$KClO_4$ = 30:10:60 increased the peak pressure of the impulse cartridge by 8.3% in the closed chamber due to the high heat output by these compositions. The test results of the peak pressure measurements are shown in Figure 6. Generally, when the pressure in the closed chamber increases, the rate of reaction also increases and the time to peak pressure decreases; similar results were recorded for these mixtures as shown in Figure 7. The time to peak pressure decreased by 14.3% for the finally selected igniter and booster compositions. The volume of the close chamber is inversely proportional to the pressure developed inside the chamber. During the design stage, the volume of the chamber was finalized for pressure measurements and it remains fixed throughout the life cycle of the product.

Table 12. Test results in a closed chamber of volume 230 cm^3 (weight of single base propellant = 4.40 g)

Existing Booster Composition		Newly prepared New-1 booster composition		Newly prepared New-2 booster composition	
Peak pressure [bar]	Time to peak pressure [ms]	Peak pressure [bar]	Time to peak pressure [ms]	Peak pressure [bar]	Time to peak pressure [ms]
131.6	39.89	143.1	49.10	139.0	30.68
134.5	42.96	137.5	36.82	143.4	42.96
129.4	36.82	142.3	24.55	143.8	30.68
131.3	36.82	138.9	36.82	143.4	36.82
130.5	42.96	138.0	42.96	143.1	30.68
130.1	36.82	136.5	42.96	139.9	30.68
Mean values					
131.2	**39.37**	**139.4**	**38.87**	**142.1**	**33.75**
		increase in peak pressure	decrease in time to peak pressure	increase in peak pressure	decrease in time to peak pressure
		6.2%	**1.3%**	**8.3%**	**14.3%**

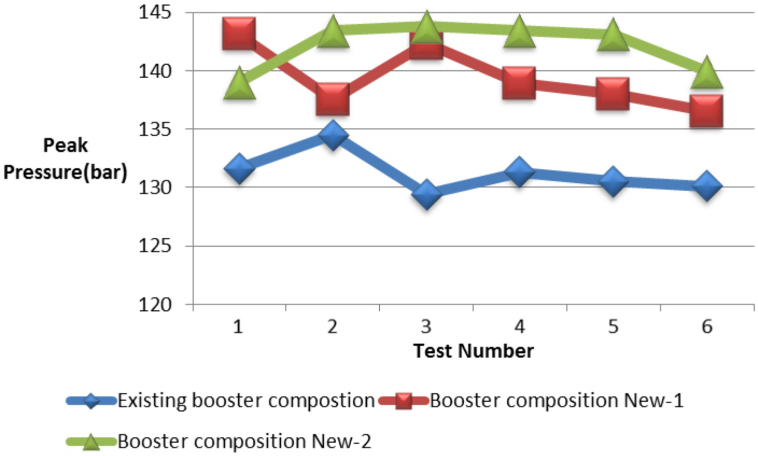


Figure 6. Plot of peak pressure for the three booster pyrotechnic compositions

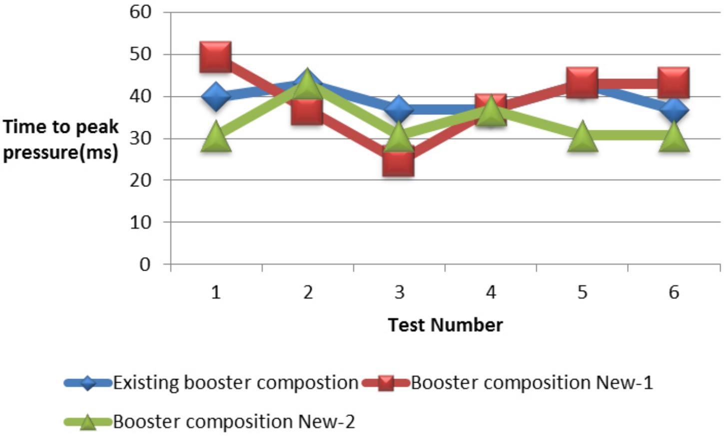


Figure 7. Plot of time to peak pressure for the three booster pyrotechnic compositions

4 Conclusions

From the analysis of all of the investigated igniter and booster pyrotechnic compositions, it was concluded that all of the newly-developed igniter and booster pyrotechnic compositions have shown promising results. Among these, the best igniter and booster compositions in terms of impulse cartridge functionality based on the peak pressure (bar) and time to peak pressure (ms) were the mixtures 60% Zr, 40% $KClO_4$ and 30% B, 10% Mg, 60% $KClO_4$, 4% additional binder, respectively. These compositions also passed all of the requisite safety tests and are considered the best compositions for impulse cartridges for the safe release of weapons from Military Aircraft.

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