



Influence of Copper Wire Heat Guides on the Combustion Velocity of Organic Based Charges for Gas Generators of Base Bleed Projectiles

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Abstract: Organic fuel based pyrotechnic charges for gas generators (GG) of Base Bleed (BB) projectiles have shown better combustion characteristics than metallic based ones. Since organic fuel based compositions are representative of energy poor pyrotechnic mixtures, they combust at lower combustion velocities. Conventional methods for heat transfer enhancement of GG charges, based on the introduction of metallic fuel components into pyrotechnic mixtures, are very successful in raising the combustion velocity, but inevitably, they also tend to force production of solid and liquid combustion products which reduce the GG charge's functionality. In this paper, the results obtained by inserting copper wires (copper wire heat guides (HG)) into organic-based gas generator charges will be presented. The aim of inserting copper wires was to enhance the combustion velocity by influencing on the thermal heat transfer of GG charges. The results have shown that copper wire heat guides had a positive influence on the GG charges heat transfer, resulting in a 15-20% rise in the combustion velocity, without any of the side effects observed in the case of the addition of metallic fuels to GG charges.

Keywords: energetic materials, pyrotechnic compositions, gas generator charge, base bleed projectiles

1 Introduction

Both organic and metallic fuel based pyrotechnic compositions for GG charges of BB projectiles have been the subjects of previous investigations. Some of the conclusions made from those investigations were:

- In the case of lactose-based compositions, a wide spectrum of linear burning velocities was obtained through improvements in their effective thermal conductivity and energy potential by altering their composition. Even the smallest percentage of iron and Fe_2O_3 added to the lactose-based compositions had a significant impact on their linear burning velocities (up to 20%). Larger portions of these additives were avoided due to their tendency to generate larger amounts of unwanted solid and liquid combustion products [1].
- Lower energy potential values, over 40% less than for magnesium-based compositions, are the result of high-energy fuel deficiency in lactose-based compositions. Furthermore, the possibility of low-temperature degradation of KClO_4 , diluted in liquefied lactose, led to 32% lower ignition temperatures for lactose-based mixtures compared to magnesium-based compositions [2].
- The highest pressure value from the combustion products, equal to 53.3 bar, was obtained for lactose-based compositions, while magnesium-based compositions produced a significantly lower pressure, 35.2 bar [2]. The pressure of the combustion products for all of the compositions was investigated in a 300 cm³ manometric bomb at atmospheric pressure and at a loading density of 0.01 g/cm³.
- In order to be able to observe the combustion stability of GG with magnesium and lactose-based fuel components, under real time usage conditions, field tests of base bleed projectiles fired from a 37 mm gun were organized. Analysis of the video recordings of those field tests have shown that, although magnesium-based GG charges were energetically stronger than lactose-based ones, their combustion stability during the flight of the projectiles was undermined. Furthermore, they are harder to ignite and burn with an intense flame blast behind the projectile's base, which could result in detection of the firing positions.

2 Theoretical Considerations

Since previous investigations had pinpointed organic-based pyrotechnic compositions as being a better solution for GG charges of high-spin stabilized

Base Bleed projectiles, the next logical step in the investigation was to adjust the compositions of the pyrotechnic mixtures to obtain the desired burning velocity and the rate of production of gaseous products. Furthermore, the thickness of the gas generator casing should be considered with utmost caution because its influence on thermal conduction from the combustion zone through the GG charge and heat dissipation to the surroundings is significant, and it must be one of the controlled parameters. Investigation results carried out with 1 and 2 mm thick aluminum tubes have shown that with thinner walls, for the same composition and charge densities, higher values of the combustion velocity (up to 45%) are obtained. Accordingly, it is very important to isolate the gas generator casing from the rest of the projectile's base in which it is inserted, in order to prevent excess heat dissipation [3].

Adjusting the burning velocity by changing the mixture's composition is commonly done by adding metallic powders (magnesium, aluminum, boron, iron, *etc.*), which has a positive effect on the mixture's ability for thermal conduction and its energy potential. Nevertheless, this solution has its side effects, manifested in the increased production of solid and liquid combustion products. Bearing in mind that the function of a GG is based on the injection of the exact amount of gaseous products in the near-wake zone behind the projectile's base [4], the production of solid and liquid combustion products diminishes the functionality of GG pyrotechnic charges.

Thus, any change in mixture composition leads to unwanted changes in the composition of the combustion products, diminishing the functional characteristics of the GG charges. Consequently, a series of tests in a search for alternative methods for accelerating the combustion process were carried out. One solution, which excelled over all of the others, and gave the best results, was the insertion of thick copper wires – heat guides (HGs) – into the GG pyrotechnic charges. The idea for the insertion of HGs into GG charges was based on their high thermal conductivity, which could be used to direct and enhance heat transfer from the combustion zone to the layers at the other end of the charge to this zone. In this manner, layers that will undergo the combustion process are being preheated to higher temperatures. So, when the time comes for those layers to be ignited, less energy from the combustion zone is needed for heating them up to the self-ignition temperature, which inevitably leads to a self-sustainable and accelerated combustion process without any changes in the composition of the combustion products.

3 Experimental

3.1 Defining a composition for investigation

For the investigation of the influence on the combustion velocity of inserted copper HGs into a pyrotechnic charge, lactose- and ascorbic acid-based pyrotechnic compositions defined in [4] were used (see Table 1).

Table 1. Pyrotechnic compositions used for the investigation

Comp. Label	Ingredient/mass portion, [%]			Oxygen balance [%]
	Fuel	Oxidizer	Binder	
Neutral oxygen balance				
010/12	Lactose/ 27.6	KClO ₄ / 69.4	Viton A/ 3.0	0.06
006/12	Lactose/ 26.8	KClO ₄ / 69.2	Viton A/ 4.0	−0.02
001/12	Lactose/ 26.1	KClO ₄ / 68.9	Viton A/ 5.0	−0.70
004/12	Lactose/ 25.2	KClO ₄ / 68.8	Viton A/ 6.0	0.06
005/12	Lactose/ 24.4	KClO ₄ / 68.6	Viton A/ 7.0	−0.02
013/12	Ascorbic acid/ 30.9	KClO ₄ / 66.1	Viton A/ 3.0	−0.26
012/12	Ascorbic acid/ 30.0	KClO ₄ / 66.0	Viton A/ 4.0	−0.33
007/12	Ascorbic acid/ 29.1	KClO ₄ / 65.9	Viton A/ 5.0	−0.46
011/12	Ascorbic acid/ 28.0	KClO ₄ / 66.0	Viton A/ 6.0	0.46
Positive oxygen balance				
002/12	Lactose/ 22.9	KClO ₄ / 71.8	Viton A/ 5.3	15.24
008/12	Ascorbic acid/ 25.9	KClO ₄ / 69.1	Viton A/ 5.0	15.52
Negative oxygen balance				
003/12	Lactose/ 29.3	KClO ₄ / 65.7	Viton A/ 5.0	−14.39
009/12	Ascorbic acid/ 32.5	KClO ₄ / 62.5	Viton A/ 5.0	−14.26

3.2 Preparation of GG charge samples for investigation of their combustion velocity

For this investigation, the insertion of the copper HGs was done in a two-phase pressing process. The pyrotechnic mixtures were pressed into aluminum tubes with 2 mm thick walls – for measuring the burning velocity, and just pressed pellets of the pyrotechnic mixtures without aluminum tubes for experiments with a thermovision camera, see Figure 1.

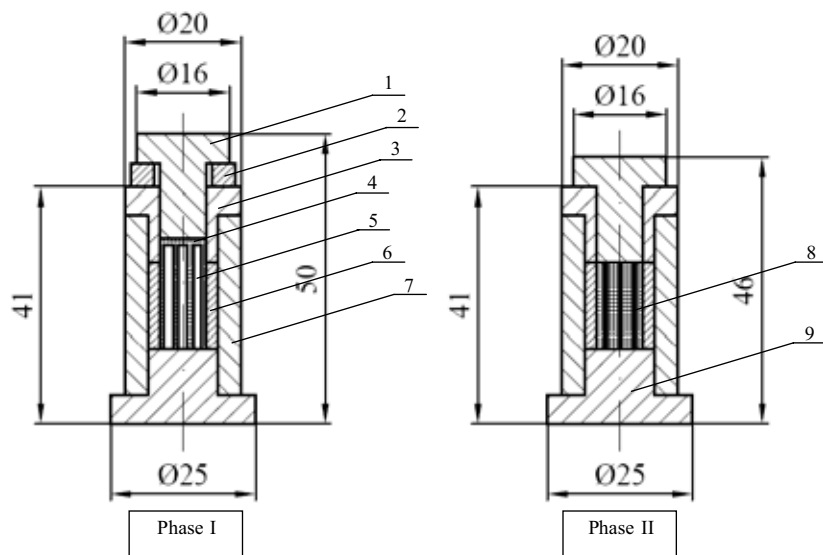


Figure 1. Two-phase tool for pressing (1 – piston, 2 – spacer, 3 – piston leader, 4 – pyrotechnic mixture, 5 – three-pin tool base, 6 – aluminum cylinder, 7 – tool body, 8 – copper wires, 9 – tool base for final pressing).

For both experiments, the first phase pressing of the pyrotechnic mixture was done with a three-pin tool base, Figure 2.

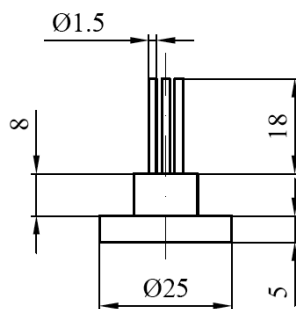


Figure 2. Three-pin tool base.

During pressing with the three-pin base (Figure 1, position 5) in a pyrotechnic charge, slots for the copper HGs are formed. After the first phase, the three-pin

base was removed and copper HGs were inserted into the slots formed in the pyrotechnic charge. After the copper HGs have been put into the formed charge slots, additional pressing, after the spacer beneath the piston has been removed, was done with a tool base without pins.

For the heat transfer investigation with a thermovision camera, pyrotechnic charges were pressed into a tool body without aluminum tubes, and released with a push-out piston.

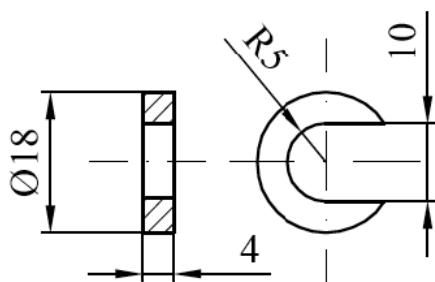


Figure 3. Spacer.

3.3 Influence of copper wires on the combustion velocity

The investigated charge density was 1.73 g/cm^3 , which required $1.3 \pm 0.01 \text{ g}$ of pyrotechnic mixture to be pressed with a “DUNKES” hydraulic press into an aluminum tube, Figure 4.

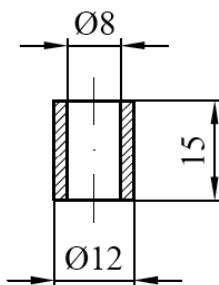


Figure 4. Aluminum tube.

The combustion time measurements were done using a VOD 811 system, produced by OZM Research s.r.o., Czech Republic, with specially modified software for the correct display of lower combustion velocities. The VOD 811 system is used for detonation and deflagration velocity measurements of explosives and slow burning propellants and pyrotechnic compositions. With a sampling

time of 1 nanosecond and a measuring interval between 10 nanoseconds and 50 seconds, the VOD 811 system has proved itself to be a very accurate and reliable device for the conduction of combustion velocity investigations. For our investigation we have nested the ends of two optic fibers, connected to the VOD 811 system, into specially formed slots in the aluminum tube body, with 10 mm spacing between them. This spacing represents the measuring range, and with information of the time needed for the combustion zone to pass these two ends of the VOD 811 optic fibers, it is used for the calculation of the combustion velocity of the composition. To ensure the validity of the investigation results, we made two additional slots, on the opposite side of the aluminum tube body, for two more optic fibers, with the same 10 mm spacing between them, and connected these to the second of the VOD's 8 available measuring channels.

In this manner we were able to measure the combustion velocity on two separate channels simultaneously, enabling us to detect any distortion of the combustion front and to take this into consideration for combustion velocity calculations. Furthermore, in order to be able to compare the results and to observe the influence of the inserted HGs on the combustion velocity of the lactose- and ascorbic acid-based charges, charges without HGs were also subjected to these investigations. The diameter of the copper wires inserted into the GG charges was 0.1 mm.

3.4 Influence of copper wires on the effective thermal conductivity of a pyrotechnic charge

In order to be able to detect changes in the effective thermal conductivity of the pyrotechnic charges, pyrotechnic mixtures were pressed into pellets without aluminum tubes, directly into the body of the pressing tool from which they were released with a push-out piston. The temperature rise in these pellets was recorded with a thermovision camera, FLIR SC620 from "FLIR Systems", Inc. The FLIR SC620 thermovision camera is designed for taking thermal images of test samples as well as measuring the temperature in specified areas of the test samples. It is a high performance camera which operates in the IR spectral region, giving thermal images of the investigated object in real time without any mechanical contact with it. For the investigation of the influence of the inserted HGs on the combustion velocity, both thermal imaging and measurements of the temperature of the test samples were obtained. In order to be able to record temperature changes without igniting the samples they were heated on test a oven, a custom-made test oven NIG S 1011H produced by "s.z.r. Elektron"-Banja Koviljaca, Republic of Serbia (Figure 5), to a predetermined temperature of 200 °C, a temperature that is below the self-ignition temperature of the

investigated samples. The diameter of the pellets for investigation was 10 mm, height 15 mm with pellet density $2.55 \pm 0.005 \text{ g/cm}^3$.



Figure 5. Activation energy test oven with automatic temperature regulation.

Test samples were carefully positioned at a specific place on the outer surface of the test oven preheated at $200 \text{ }^{\circ}\text{C}$ and recorded with the FLIR SC620 thermovision camera for 3 minutes.

4 Results and Discussion

4.1 Influence of the inserted copper wires on the combustion velocity

The investigated conditions were:

- charge density 1.73 g/cm^3 ,
- chamber wall thickness 2 mm,
- lactose-based charges with and without copper wires.

The combustion velocity results for the prepared pyrotechnic samples are shown in Table 2.

Table 2. Copper wire influence on the combustion velocity investigation

Composition Label	ρ [g/cm ³]	Burning velocity [mm/s]				BVa [mm/s]	Rise in burning velocity, [%]
001/12 (WCHG)*	1.73	0.79	0.77	0.79	0.83	0.80	15.94
001/12**		0.70	0.66	0.70	0.71	0.69	
004/12 (WCHG)*		0.77	0.76	0.78	0.79	0.77	14.92
004/12**		0.68	0.67	0.64	0.67	0.67	
005/12 (WCHG)*		0.71	0.79	0.76	0.74	0.75	17.19
005/12**		0.64	0.63	0.63	0.64	0.64	
006/12 (WCHG)*		0.77	0.81	0.83	0.81	0.80	17.65
006/12**		0.69	0.67	0.66	0.70	0.68	
010/12(WCHG)*		0.81	0.79	0.87	0.79	0.81	14.08
010/12**		0.73	0.70	0.68	0.74	0.71	

* (WCHG) – with Copper Heat Guide; ** results presented in [4]; BVa – average value of burning velocity.

As can be seen from the data in Table 2, samples with copper heat guides inserted into the pyrotechnic charges had higher values of the burning velocity than those without copper wires. This rise in burning velocity was, as expected, very consistent, from 14.08 to 17.65%, and is related to the differences in mixture compositions (different portion of binders, oxygen balance, *etc.*). This rise in burning velocity was also achieved with the introduction of metallic powders to the mixture compositions, but, as was mentioned in [1], the combustion products of those mixtures were rich in solid and liquid products which had a negative influence on the GG charge performance.

4.2 Influence of copper wires on the effective thermal conductivity of pyrotechnic charges

As was already stated in the Experimental, pyrotechnic pellets without aluminum tubes, both with and without inserted HGs, were placed at a specific place on the outer surface of the activation energy measuring oven, preheated to 200 °C. Changes in temperature, as well as thermal imaging of the investigated samples, were monitored and measured for a predetermined sample area close to the heat source. The measuring area is marked with a rectangle beneath the thermal image.

Bearing in mind that GGs of 37 mm BB projectiles have to attain stable combustion for 20 seconds, this time interval was the subject of a more detailed analysis, whilst thermal imaging throughout the whole investigated period was taken into consideration for drawing conclusions relating to the influence of

inserted HGs on the effective thermal conductivity of pyrotechnic charges in general. Thus, we can consider the magnitude of the influence of HGs on the ignitibility of layers directly in front of the combustion zone, as well as the overall influence on the effective thermal conductivity of the charge.

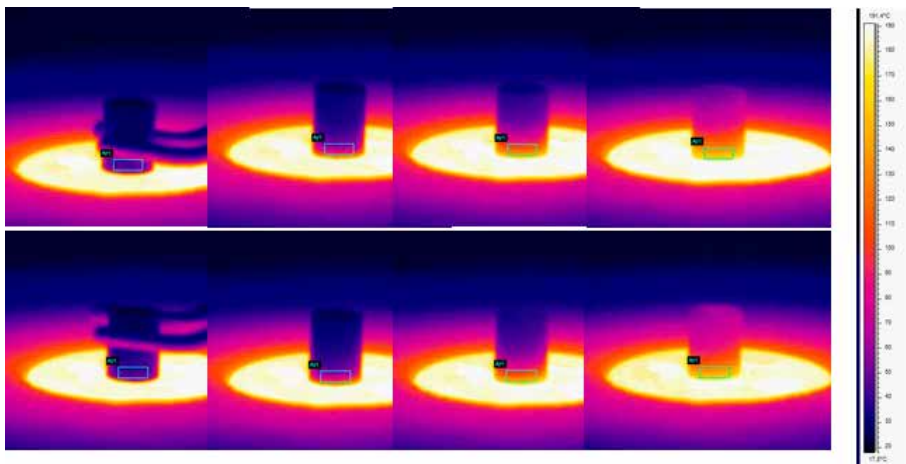


Figure 6. Thermal images of 001/12 mixture pellets at 0, 10, 60 and 180 s, reading from left to right (first row – pellets without HGs, second row – pellets with inserted HGs).

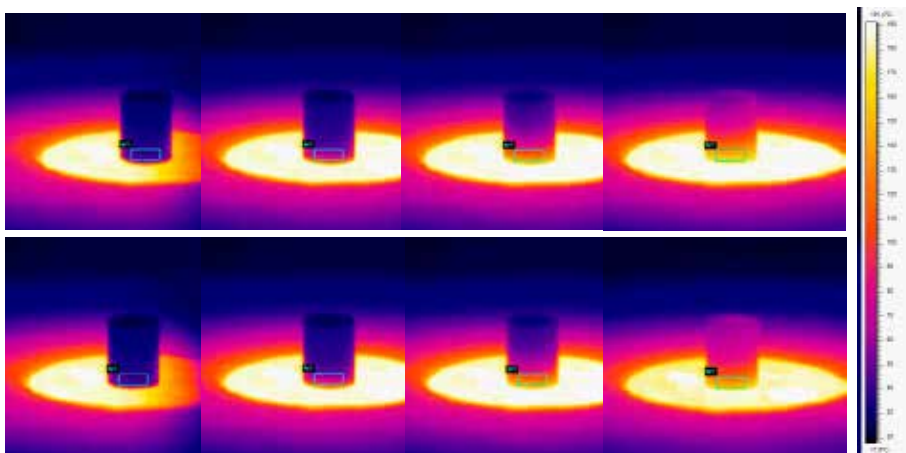


Figure 7. Thermal images of 007/12 mixture pellets at 0, 10, 60 and 180 s, reading from left to right (first row – pellets without HGs, second row – pellets with inserted HGs).

In order to be able to obtain valid data comparisons, Figures 6 and 7 represent mixtures 001/12 and 007/12, which have neutral OB and 5% binder portions. As can be seen from these images, both pellets with inserted copper HGs experienced a significant rise in the temperature of the top layers, opposite to the heating zone. Also, samples with copper wires had better temperature distribution throughout the sample volume than samples without copper wires. This conclusion is more obvious when the final thermal image of both samples for the specific pyrotechnic compositions, with and without inserted HGs, are compared. For example, if we look at the final thermal image of the sample without inserted HGs in the first row of Figure 7, we can see that top layers of that sample have a darker shade of blue than the sample with inserted HGs, the final thermal image in the second row of Figure 7, indicating lower temperatures in those layers. Also, looking again at Figure 7, for the pellet with the inserted HGs (the final thermal image in the second row of Figure 7), the formation of an inner zone around the region where the HGs were inserted, with a significantly higher temperature than the rest of the pellet, additionally confirms the claim that the inserted HGs have a positive effect on the overall heat conducting ability of the charge. This conclusion is supported by the fact that the thermal image of a similar pellet, but without HGs (the final image in the first row of Figure 7), lacks a higher temperature zone. Other thermal images from the rest of the pyrotechnic mixtures from Table 1, will not be shown in this paper because they are consistent with the rules established from Figures 6 and 7.

The influence of the inserted HGs on the preheating of the layers in front of the “combustion” zone, in our case the heating zone, will be analyzed by comparison of the recorded maximum temperatures in the specified sample zone, marked with a rectangle, seen in Figures 6 and 7.

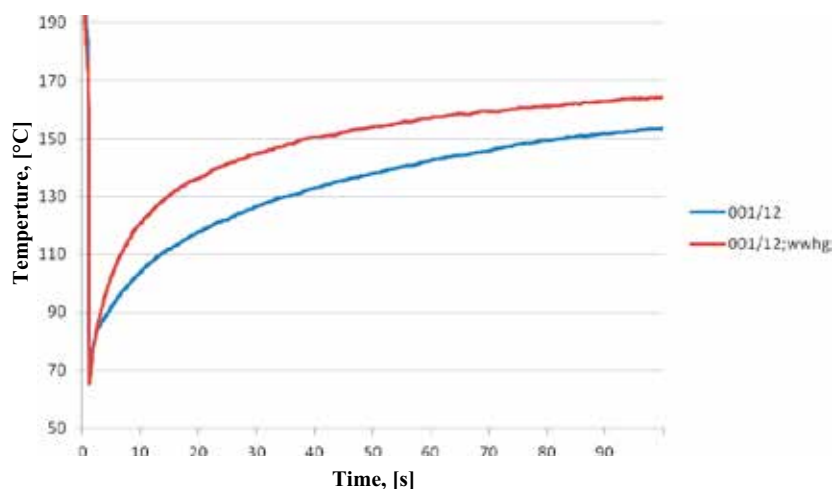


Figure 8. Temperature rise as a function of time for the 001/12 pyrotechnic mixture samples, both with (red line) and without copper HGs (blue line).

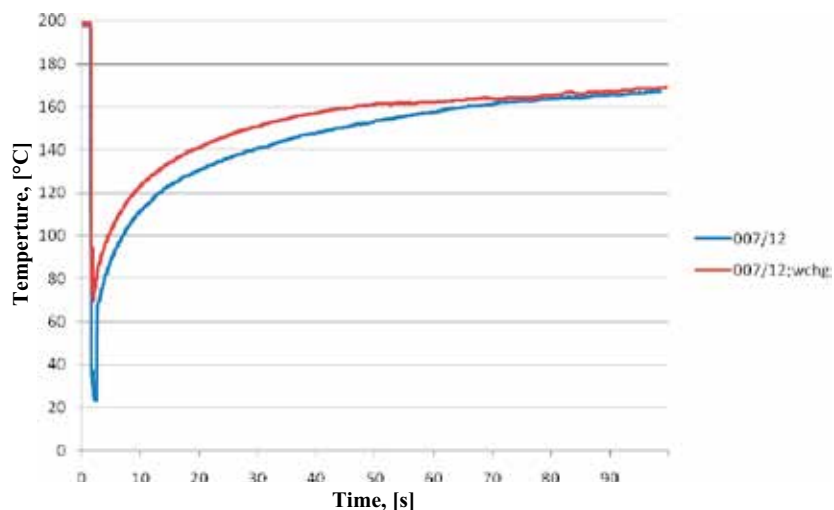


Figure 9. Temperature rise as a function of time for the 007/12 pyrotechnic mixture samples, both with (red line) and without copper HGs (blue line).

Several facts from Figures 8 and 9 are obvious. The first is that the rise in temperature for a sample with copper wires had a steeper rise in temperature within the first 60 seconds of measurement.

The maximum temperature difference between samples with (red line) and without copper HGs (blue line) is observed during the first 40 seconds of heat treatment, after which the curves tend to converge; this is more obvious in Figure 9.

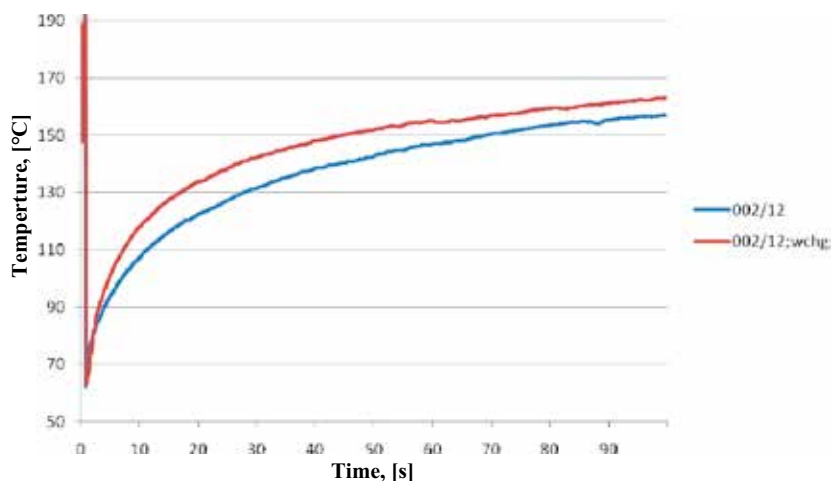


Figure 10. Temperature rise as a function of time for the 002/12 pyrotechnic mixture samples, both with (red line) and without copper HG (blue line).

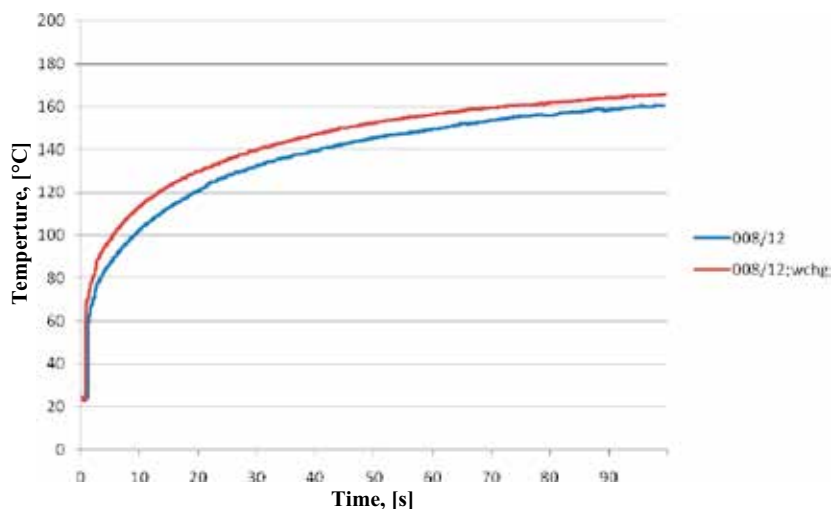


Figure 11. Temperature rise as a function of time for the 008/12 pyrotechnic mixture samples, both with (red line) and without copper HG (blue line).

Figures 10 and 11, which represent two more lactose- and ascorbic acid-based compositions, simply proves the consistency of the positive influence of copper HGs on heat transfer in the investigated pellets.

5 Conclusions

Fine tuning problems with the combustion velocity of low energy organic-based pyrotechnic charges, without changes in their mixture and combustion products compositions, have been successfully resolved in this paper by the insertion of copper wire heat guides into pyrotechnic charges for GG.

The insertion of copper HGs into the investigated samples of lactose- and ascorbic acid-based pyrotechnic mixtures leads to:

- A consistent increase in the combustion velocity for all of the investigated samples, from 14% (for 010/12 composition) to almost 18% (for 006/12 composition).
- The temperature difference between the observed zones of the investigated samples, of the same pyrotechnic composition, with or without inserted copper heat guides, goes from 7 °C (Figure 11 at 40 s.) to 18 °C (Figure 8 at 37 s.).

Thermal images, made with a thermovision camera, confirm all earlier claims, showing the formation of an inner zone, around the region where the HGs are inserted, with significantly higher temperatures than the rest of the pellet. This higher temperature zone is not present in samples without copper HGs, which emphasises the positive effect of the copper HGs on the overall effective thermal conductivity of the charge.

Overall, by introducing copper HGs to the pyrotechnic charges we have successfully enhanced their combustion velocity without any adjustments to the mixture ingredients or the composition of their combustion products. Another advantage of this method lies in the fact that it preserves the production of low mass combustion products from these charges, and avoids the use of inner holes for the enhancement of the combustion surface, which reduces the mass of the pyrotechnic mixture available for combustion.

All of the investigated data concurs with the conclusion that this method is a desirable resource for combustion velocity management of GG charges without any of the unwanted side-effects encountered with other conventional methods.

6 References

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