



Research paper / Praca doświadczalna

Ballistic tests of double-based propelling charges with different carbon black content

Badania balistyczne nitroglicerynowych ładunków napędowych z różną zawartością sadzy

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Abstract: Nitrocellulose and nitroglycerin are the main components of double-base propellants comprising up to 95% of their total mass. A chemical stabiliser and a burn rate modifier are required components, added in amounts of several percent. The study analyses the effect of carbon black content, contributing less than 1% of the propellant mass, on the burning rate of differently shaped propelling charges. The experiments, carried out on high energetic, double-base propelling charges, showed that the carbon black content significantly affects the burning rate of the propelling charge in the rocket motor chamber.

Streszczenie: Głównymi składnikami nitroglicerynowych paliw raketowych są nitroceluloza i nitrogliceryna stanowiące do 95% masy. Obowiązkowym składnikiem jest również stabilizator trwałości chemicznej, zwykle centralit, w ilości kilku procent. Częstym składnikiem jest niskotopliwy dinitrotoluen (mieszanina izomerów) w ilości około 10%. Wymienione składniki w procesie technologicznym ulegają homogenizacji tworząc jednorodny stały żel o właściwościach termoplastycznych. Składnikami o zawartości do 3% są modyfikatory prędkości palenia, zwykle sole i tlenki metali ciężkich jak Pb, Cu, Cr. W pracy zbadano wpływ zawartości sadzy, składnika o najmniejszej zawartości w paliwie, stanowiącego poniżej 1% masy paliwa raketowego. Wykazano eksperymentalnie na przykładzie ładunku wykonanego z wysokokalorycznego paliwa nitroglicerynowego, że zawartość sadzy w paliwie wywiera silny wpływ na prędkość palenia ładunku w komorze silnika raketowego.

Keywords: double-base propellant, carbon black, ballistic parameters

Słowa kluczowe: paliwo nitroglicerynowe, sadza, parametry balistyczne

1. Introduction

A. Nobel (1887) used a low volatile solvent – nitroglycerin – as a gelatinizing agent for nitrocellulose to obtain a homogenous, thermoplastic product known as ballistite or double-base propellant. An example of a double-base propellant with a high gross calorific value is:

- nitrocellulose: 58%,
- nitroglycerin: 37%,

- stabilizing agent: 2.5%,
- catalyst and petroleum jelly: 2.5%.

Double-base propellants are made using low-viscosity nitrocellulose with 12.2% nitrogen content, which is completely soluble in nitroglycerin. A pre-mixture of the components is prepared in a water suspension where nitroglycerin is absorbed onto the nitrocellulose fibres. After filtering, a fibrous, non-combustible semi-finished product containing approximately 30% water, known as powder pulp, is obtained. The powder pulp can be stored and transported safely under production plant conditions. To obtain the propellant (or propellant powder), the water is removed in a rolling mill at 60 °C, where the nitrocellulose gelatinization begins. The end product, a 1-10 mm thick film, is obtained by multiple rolling at 95 °C, cutting into several millimetre long plates and graphite coating to obtain the finished double-base propellant. The good thermoplastic properties of the product enable it to be formed as tubes, cylinders, stars *etc.* by extrusion. Ballistite is also a conventional propellant formed into propelling charges for rocket engines by hot extrusion (Figure 1) [1-7]. One of the propellant components, added in quantities of less than 1%, is carbon black, used as an modifier in the combustion process [8].

Since similar studies could not be found in national literature, one of the requirements of the study was determining the effect of carbon black content on the burning rate of a homogenous “*Bazalt*” propellant. The purpose was to find a way of increasing the burning rate of propelling charges made using “*Bazalt*” propellant for ejection seats manufactured by Martin Baker and under license in Romania. The second purpose of the study was to determine the effect of carbon black content in the “*Bazalt*” propellant on the burning rate of different shaped propelling charges.

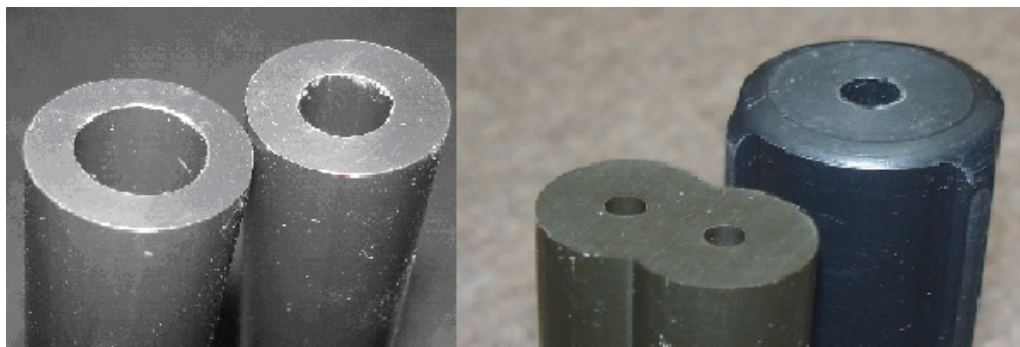


Figure 1. Shapes of the propelling charges for rocket motors made of double-base propellant

2. Technology of double-base propellant and propelling charges

The homogenous propellant used in the test is characterized by its high gross calorific value of 4463 ±42 kJ/kg (1065 ±10 kcal/kg). Table 1 shows the chemical composition of “*Bazalt*” propellant.

Table 1. Chemical composition of “*Bazalt*” propellant

Component	Function	Content [%]
Nitrocellulose with 12.6% N content	high-calorific value binding agent	57.5 ±1
Nitroglycerin	high-calorific value gelatinizing agent	36.7 ±0.7
Centralite II	chemical stabilizer	2.4 ±0.2
Catalyst (organic acid salt)	burning rate modifier	3.0 ±0.2
Carbon black	opacifier	0.4 ±0.1

The first two basic components forming a homogenous thermoplastic structure determine the energy performance of the propellant. Centralite is a chemical stabilizer which ensures long term safe utilisation of the powder pulp, the propellant and the propelling charges made, using those components. The catalyst guarantees stable burning conditions with a preferred linear burning rate under a wide range of pressure within the rocket engine chamber. Anti-resonance agents (e.g. chalk) or agents reducing the size and temperature of the flame at the nozzle (e.g. potassium sulfate, K_2SO_4) are also used as modifiers of the propellant burning process.

Carbon black, distributed evenly in the volume of the homogenous propellant, radically reduces its transparency for propagation of electromagnetic radiation in the IR, visible and UV spectrum. Carbon black, added in quantities of fractions of a percent to the homogenous propellant, changes the qualitative properties of the mechanism of heat transfer from the burning zone in the direction of the burning front. This phenomenon is currently being studied [9], since determining the effect of carbon black and its different species, e.g. fullerenes, on the burning process of homogenous propellants has a significant applicability.

A fruitful partnership with ZPS Gamrat in Jasło, yielded production batches of “Bazalt” propellant with the composition specified in Table 1, containing different quantities of carbon black (N220 grade by Degussa Frankfurt), with an extended surface of $105 \text{ m}^2/\text{kg}$, measured in a nitrogen atmosphere. The carbon black content was: 0.1, 0.4, 0.6 and 0.7%. No higher carbon black content was used, since at 0.7% a limiting viscosity of the propellant rolled at $95 \text{ }^\circ\text{C}$ was observed, posing the risk of ignition during homogenization. Different shaped charges were made from the propellant batches with different carbon black content. The charges were machined to the dimensions specified in Figure 2 and were used in the ballistic tests.

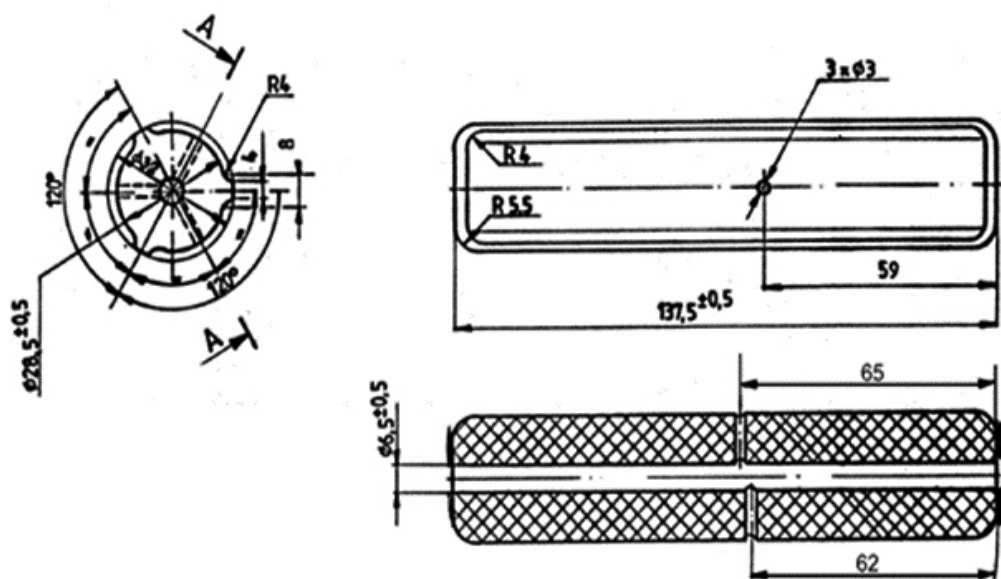


Figure 2. Geometric dimensions of charges made with “Bazalt” propellant

3. Ballistic tests of propelling charges

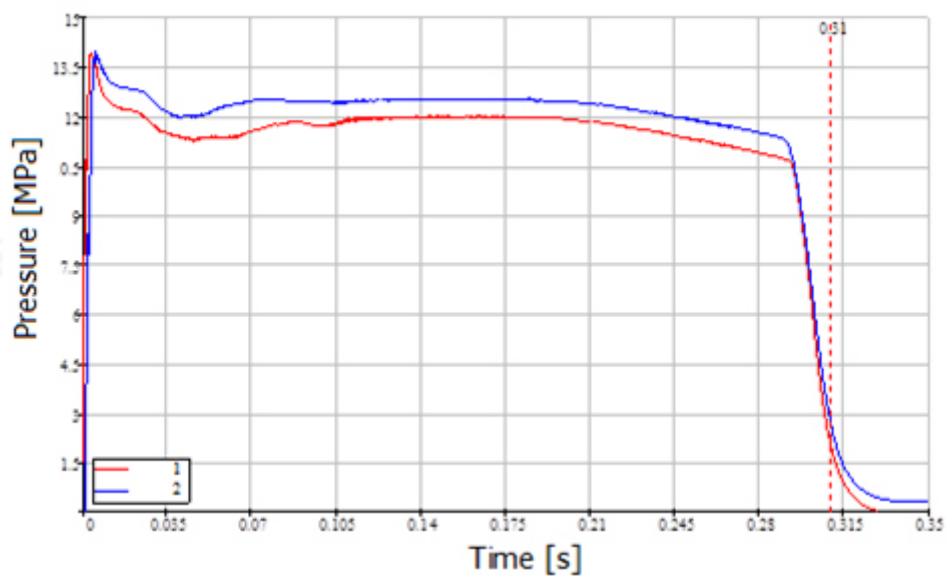
Since the burning rate of homogenous propellants depends on the temperature of the test charges, the burning rate decreases with decreases in charge temperature. To clearly determine the relationship between the burning rate and the carbon black content, the tests were carried out at an extreme operating temperature of $-35\text{ }^{\circ}\text{C}$. The ballistic tests of individual charges were carried out using a ballistic test stand, see Figure 3. The tests were carried using the facility at the Ballistics Laboratory, ITU WML WAT (Military University of Technology). In each test, time vs. chamber pressure and thrust were recorded using PCB Piezotronics (USA) sensors and a PCMCIA II module connected to a laptop.



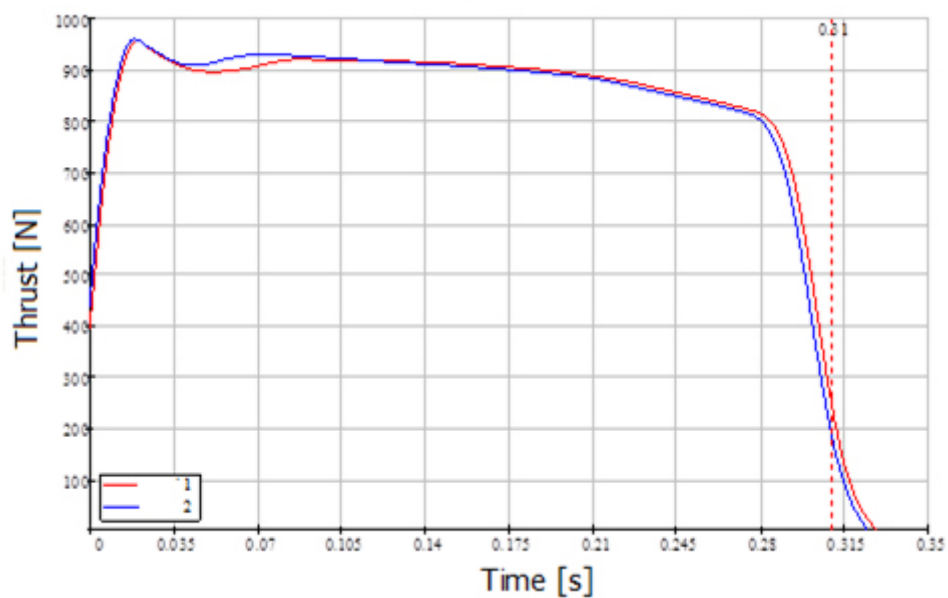
Figure 3. A ballistic test rocket motor installed on a vertical ballistic test stand – view from the engine nozzle side

The propelling charges with differing carbon black content used in the test rocket motors were cooled to $-35\text{ }^{\circ}\text{C}$ and soaked for 6 h. Figure 4 shows the output of the ballistic parameters for charges with 0.7% carbon black content. The diagrams also include the charge burning time, from ignition to pressure drop in the combustion chamber to 2.2 MPa.

The extended tests were carried out for charges with 0.6% carbon black content (Fig. 5) to determine the effect of internal charge diameter on the burning time. The charges from the production batch with an internal diameter of $\Phi_w = 6\text{ mm}$ were machined to a diameter of $\Phi_w = 7\text{ mm}$ to reduce the charge mass by 3 g to 133 g – a value within the permitted range for an individual charge. Increasing the internal diameter by 1 mm resulted in a significant decrease in the burning time of 0.04 s, *i.e.* by over 10% (test no. 3 and 4, Fig. 5).



(a)



(b)

Figure 4. Time-pressure (a) and time-thrust (b) diagram for charges with 0.7% carbon black content for two charges burned at $-35\text{ }^{\circ}\text{C}$

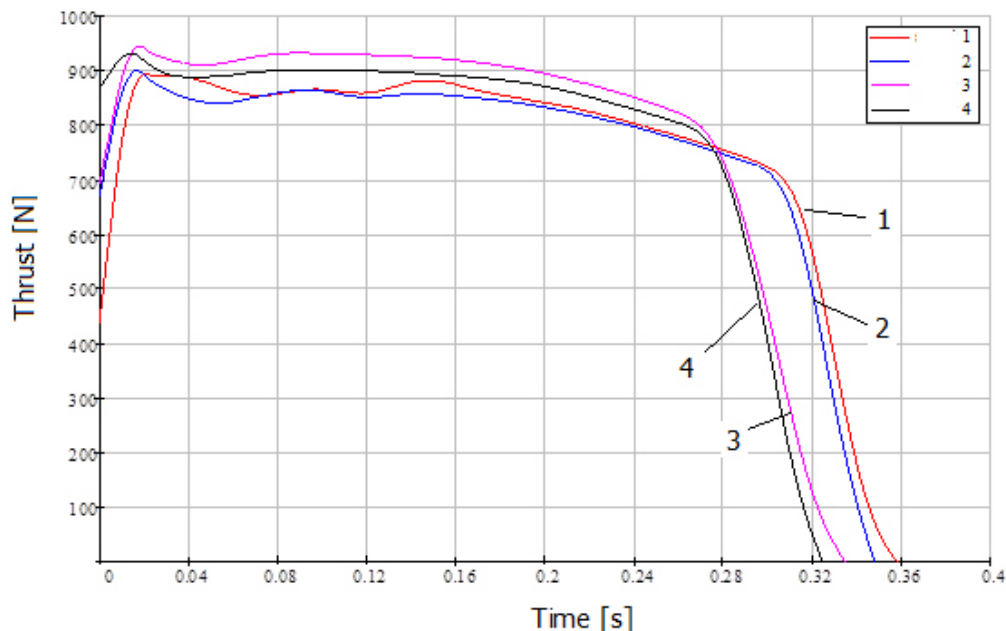


Figure 5. Time-thrust diagram for charges with 0.4% carbon black content:

- test no. 1 and 2: charge with $\Phi_w = 6$ mm hole,
- test no. 3 and 4: charge with $\Phi_w = 7$ mm hole

4. Result analysis

The ballistic tests of type CIII charges made of homogenous propellant with different carbon black content showed the significant effect of this components on the linear burning rate. Table 2 shows the test results. An increase in carbon black content in the propellant composition results in a significant increase in burning rate, which was a desirable outcome of the study. The main goal was to obtain a homogenous propellant with a high burning rate, which at -35 °C would achieve a burning time of the propelling charge shown in Figure 2, of less than 0.32 s. For a carbon black content of 0.6% selected for the technological process, additional charges with the internal charge diameter increased by 1 mm, were prepared. This change significantly reduced the charge burning time as a result of the decrease in combustible layer thickness. Table 2 shows the experimental data for the effect of carbon black content in the double-base propellant, on the burning rate of the propelling charges. Figure 6 shows the graphical representation of the relationship between the burning rate of the charge and its carbon black content.

Table 2. The burning rates of propelling charges with different carbon black content

Parameter	Carbon black content [%]			
	0.1	0.4	0.6	0.7
Charge burning time [s]	0.45	0.36	0.33	0.31
Burning rate [mm/s]	12.2	15.3	16.7	17.7

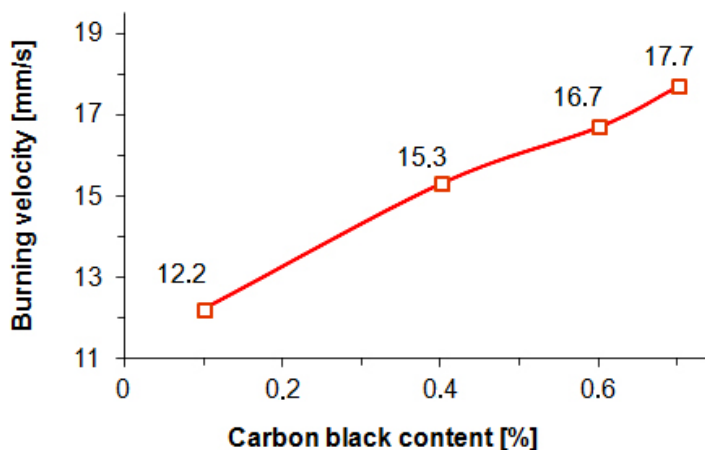


Figure 6. Burning rate of the propelling charge as a function of carbon black content

5. Conclusions

- ◆ A potential solution to increasing the burning rate of dual-base propellants is to increase the content of a minority component (carbon black), used as a technological additive. An increase in carbon black content to 0.6% results in a significant increase in the linear burning rate to a value close to the required charge parameters.
- ◆ The addition of carbon black qualitatively affects the mechanism of heat transfer from the burning zone to the heated propellant layer. At increased carbon black content, the heat from the burning zone is accumulated in the thinner heated layer, resulting in a rapid increase in temperature and an earlier ignition.
- ◆ An increase in carbon black content to over 0.7% is practically impossible due to the difficulties in propellant homogenization processing in a rolling mill and the high risk of ignition of the rolled propellant. The physical properties of a given grade of carbon black should be determined and compared with those of other internationally available grades.

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Received: May 27, 2020

Revised: November 17, 2020

Published first time online: November 25, 2020