PROBLEMY MECHATRONIKI
UZBROJENIE, LOTNICTWO, INŻYNIERIA BEZPIECZEŃSTWA

ISSN 2081-5891 **10, 2 (36), 2019, 55-68**

PROBLEMS OF MECHATRONICS
ARMAMENT, AVIATION, SAFETY ENGINEERING

Investigations of the Influence of Ignition on the Dynamic Vivacity of Propellants

Radosław TRĘBIŃSKI*, Zbigniew LECIEJEWSKI, Zbigniew SURMA

Military University of Technology, Faculty of Mechatronics and Aerospace,
2 gen. Sylwestra Kaliskiego Str., 00-908 Warsaw, Poland
Corresponding author's e-mail address and ORCID:
radoslaw.trebinski@wat.edu.pl; https://orcid.org/0000-0002-4659-2318

Received by the editorial staff on 13 July 2018
The reviewed and verified version was received on 14 November 2018

DOI 10.5604/01.3001.0012.9670

Abstract. The paper presents an attempt to determine the dynamic vivacity functions of propellants with taking into account a parallel burning of the black powder igniter and the tested propellant. The approach is based on presented results of closed vessel tests, proving that the burning of the tested propellant starts before complete burning of the black powder igniter. Basing on closed vessel tests results for black powder, its dynamic vivacity function was determined. It was used for a prediction of the partial pressure of black powder combustion products in the case when black powder was used as an igniter. Dynamic vivacity curves are compared with the dynamic vivacity curves calculated at the assumption that the combustion of the main charge starts after the complete burning of the igniter. Obtained results show that the considered approach fails due to a very complex interaction between the igniter and the tested propellant.
Keywords: internal ballistics, dynamic vivacity, ignition

This work has been compiled from the paper presented during the 12nd International Armament Conference on Scientific Aspects of Armament & Safety Technology, Jachranka, Poland, September 17-20, 2018.

1. INTRODUCTION

In investigations described in the monography [1] and in [2] it was discovered, that changing the mass of the igniter (black powder) it is possible to influence considerably the full process of the burning of a propellant in the closed vessel test. The shapes of the dynamic vivacity curves served as an evidence of this. The curves were determined at the assumption, that the black powder had been burned completely before the ignition of the main charge. However, in the literature ([3]) some information can be found, that the assumption of the ignition of the main charge after the attaining of the ignition pressure is not always fulfilled. It means that the main charge may burn for a time parallel with the igniter. In such a situation, the dynamic vivacity curves, determined at the assumption of the ignition of the main charge after the complete burning of the igniter, can be a reason of a wrong assessment of the investigated propellant properties. It has special importance at the investigations of the LOVA type propellants, that undergo a delayed ignition in comparison to the single and double based propellants. This was the reason of performing investigations and analysis with the aim to verify the hypothesis of the simultaneous burning of the igniter and the main charge and elaborating a method of the determining the dynamic vivacity curves for this case.

2. MATERIALS AND METHODS

2.1. Experimental tests and materials

In the first stage of the analysis results of the closed vessel tests described in [1], [2] and [4] were used. Details of the experimental procedure are described therein. In the second stage closed vessel tests for LO5460 (JA-2) propellant and an experimental LOVA type propellant were performed in a closed vessel having 200 cm^3 capacity. Characteristics of used propellants are given in Table 1. Additionally, pressure courses at the burning of black powder igniters alone were recorded.

2.2. Method of analysis

Microscopic examinations of the used black powder D-2 demonstrated considerable variations of the shape and size of its grains ([4]). Therefore, the shape function cannot be used to determine the burning rate of the propellant. The only way to determine its burning rate is to use the physical law of burning introduced in [5], with some modifications proposed in [6]:

Table 1. Characteristics of propellants used in closed vessel tests

Parameter	**WT**	**15/1TR**	**9/7**	**4/1**	**NPŁ 10-13**	**D-2**	**LO5460**	**SC**
type	single	single	single	single	double	black	double	LOVA
grain shape	tubular	tubular	tubular	tubular	tabular	irregular	tubular	tubular
perforation	1	1	7	1	0	0	7	7
length [mm]	1.85	75	12.3	6.2	1.2 x 1.2	-	15.5	15.5
diameter [mm]	0.8	4.95	5.41	0.99	-	-	8.9	8
perforation diam. [mm]	0.15	1.91	0.47	0.25	-	-	0.546	0.5
density [kg/m^3]	1600	1580	1610	1550	1630	1860	1570	1600
force [kJ/kg]	1038	884	961	1001	1119	298	1154	1208
covolume [dm^3/kg]	1.154	1.567	1.230	1.339	1.035	0.937	1.001	1.025

$$\frac{dz}{dt} = G(z)\, p_0 x^n, \quad x = \frac{p}{p_0} \tag{1}$$

The symbol z means the relative burned volume of the propellant, t means the time, G means the dynamic vivacity, p_0 means the reference pressure 0.1 MPa, p means pressure, n means the exponent in the burning law. The value of the exponent n is determined by using the following relation resulting from (1):

$$w(z, \log x) = \log\frac{dz}{dt} = \log\left[p_0 G(z)\right] + n \log x \tag{2}$$

For the given value of z the function $w(z, \log x)$ is a linear function of $\log x$. Approximating the dependence of w on $\log x$ for given values of z, the value of the exponent n can be calculated. The values of n for z = 0.3, 0.4, 0.5, 0.6, 0.7 are determined and the mean value is calculated. In order to calculate the values of z and dz/dt the following relations are used:

$$z = \frac{b_1 p_s}{f + b_2 p_s}, \quad p_s = p - p_z, \quad b_1 = \frac{1}{\Delta} - \frac{1}{\rho}, \quad b_2 = \eta - \frac{1}{\rho} \tag{3}$$

$$\frac{dz}{dt} = \frac{dz}{dp}\frac{dp}{dt} \tag{4}$$

$$\frac{dz}{dp} = \frac{b_1 f}{\left(f + b_2 p_s\right)^2} \tag{5}$$

The symbol f means the force of the propellant, Δ means the loading density, ρ means the solid propellant density, η means the covolume, p_z means ignition pressure.

Basing on pressure records obtained at combustion of D-2 propellant (black powder) the value of the exponent n_z and the function $G_z(z)$ are determined. Then, they are used in analysis of pressure records obtained at combustion of a given propellant, ignited by the D-2 igniter. The procedure is as follows. We choose an initial value of pressure p_1. As a rule, it is of order of 0.03-0.05 MPa (in a fact it is an overpressure over the atmospheric pressure p_0, roughly 0.1 MPa). Then we calculate the initial value of the relative burned volume of the black powder:

$$z_{z1} = \frac{p_1}{p_{z\max}} \tag{6}$$

The symbol $p_{z\max}$ means the nominal ignition pressure, corresponding to the full combustion of the igniter. The consecutive values of z_z and the partial pressure of the products of combustion of the igniter are calculated by the following formulae:

$$z_{zi+1} = G_z\left(z_{zi}\right) p_0 \left(\frac{p_i}{p_0} + 1\right)^{n_z} \Delta t + z_{zi} \tag{7}$$

$$p_{zi+1} = p_{z\max} z_{zi+1} \tag{8}$$

If p_i is larger than p_{zi}, the partial pressure of the products of combustion of a tested propellant is calculated:

$$p_{si} = p_i - p_{zi} \tag{9}$$

Then we can use the formulae (3)-(5) for calculating the relative burned volume of the tested propellant and the derivative dz/dt. They values are used for calculating the dynamic vivacity function of the tested propellant:

$$G\left(z_i\right) = \frac{\left(\frac{dz}{dt}\right)_i}{p_0 \left(\frac{p_i}{p_0}\right)^n} \tag{10}$$

3. RESULTS AND DISCUSSION

3.1. Dynamic vivacity of black powder

Closed vessel tests for D-2 propellant were performed with the loading density values equal to 50, 100 and 150 kg/m^3. Obtained pressure records were used to determine the values of the exponent n_z determined for z = 0.3, 0.4, 0.5, 0.6 and 0.7. These values are presented in Fig. 1. The mean value is n_z = 0.210±0.026 (95% confidence level).

The value of n_z is larger than the value 0.164±0.017 determined in [7] on the basis of the strand burner tests results for the pressure range 0.3-10 MPa. However, it is much lower than the value 0.813 determined in [8]. In Ref. [9] results of measurements of the black powder burning rate published in several works were collected and presented in one figure. Values determined from that figure are presented in Fig. 2. Unlike in Ref. [9] the data were approximated by a linear function. The value n_z = 0.209 was obtained, very close to the value determined in this work. Therefore, the following burning law of black powder can be proposed:

$$r = \beta \left(\frac{p}{p_0} \right)^{n_z}, \ \beta = 1.2, \ n_z = 0.209 \quad [\text{cm/s}] \tag{11}$$

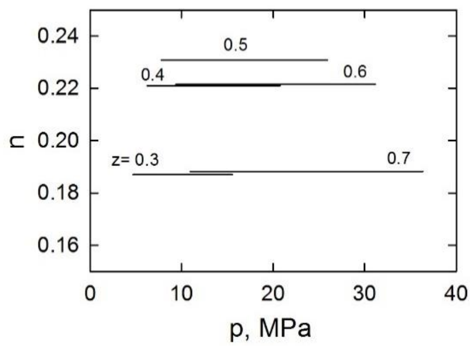

Fig. 1. Results of determining the value of the exponent n_z for z = 0.3, 0.4, 0.5, 0.6, 0.7

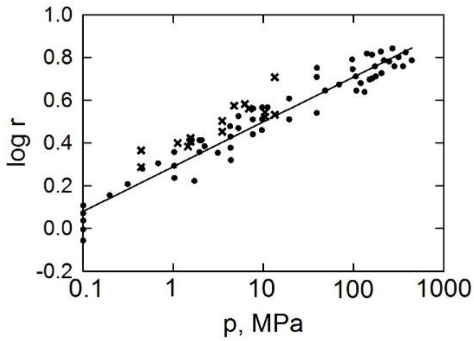

Fig. 2. Dependence of the burning rate of black powder on pressure: circles [9], crosses [7]

Results of the burning rate measurements published in [7] are positioned over the regression line in Fig. 2. Possibly, it is caused by the low density of pressed samples used in [7]. Due to porosity of the samples the burning rate values are higher. The obtained in [7] value n_z = 0.164 is perturbed by the influence of the porosity on the burning rate. In [10] the following formula was proposed for the mass burning rate:

$$r_M = 2.3 \left(\frac{p}{p_0} \right)^{0.216} \quad [\text{g/cm}^2\text{s}] \tag{12}$$

The density of used samples was not given. Using the mean value of measurement results from Table 3 in [11] 1.86±0.02 g/cm^3 and dividing 2.3 by it, the value β = 1.24 cm/s is obtained. It is close to the value of the coefficient β in Eq. (11). Basing on Fig. 3 in [12] the following values can be assessed: n_z = 0.19, β = 1.37 cm/s.

After confrontation of the data we can conclude that Eq. (11) approximates well the black powder burning rate in the pressure range 0.5 – 100 MPa. It overestimates the burning rate at the atmospheric pressure. Basing on Fig. 3 in [12] the following values can be proposed for the pressure range 0.1-0.5 MPa: n_z = 0.45, β = 0.9 cm/s. In this work the value n_z = 0.21 was chosen for the whole range of pressure values. This approximation may cause an overestimation of the value of $G_z(z)$ for pressure values lower than 0.5 MPa. However, other factors influence values of $G_z(z)$ much stronger.

The shapes of dynamic vivacity function for three loading density values are shown in Fig. 3. The functions were approximated by the third order polynomial and then averaged for all values of the loading density. The averaged function was approximated by a third order polynomial. It is shown by the dotted line in Fig. 3. Its analytical form is as follows:

$$G_z(z) = 900z\left(3 - 4z + z^2\right), \quad \left[\left(\mathrm{MPa}\cdot\mathrm{s}\right)^{-1}\right] \tag{13}$$

$G_z(z)$ functions have a form that is typical for deterred propellants. However, used black powder is not deterred. The graphite coating cannot influence the burning process in such an extent. Two explanations can be proposed.

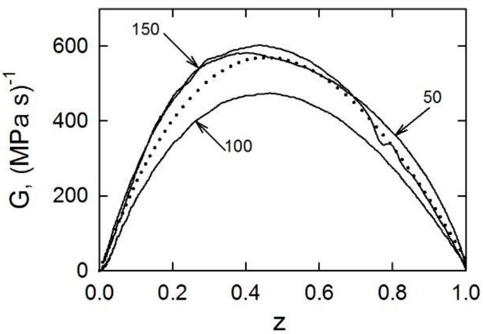

Fig. 3. $G_z(z)$ functions determined for the loading density values 50,100, 150 kg/m^3 (solid lines), dotted line – approximation (13)

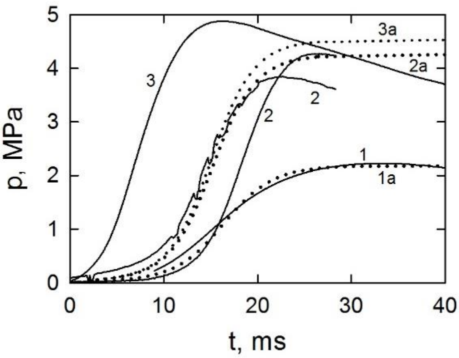

Fig. 4. Comparison of recorded (solid lines) and calculated (dotted lines) pressure courses for combustion of the igniter alone

The closed vessel used in investigations presented in [4] is relatively long – 19.3 cm (diameter 3 cm). During the tests it was positioned horizontally, and the black powder was evenly distributed on its bottom. The powder bed was ignited by an ignition head, so the initiation was localized at one of the ends of the vessel. In accordance with the results of measurements presented in [13] the flame spreading along a bed of black powder under atmospheric pressure is of the order of 1 m/s. The value 60 cm/s was given in [9].

However, under the pressure 4 MPa the spreading rate of the flame is equal 2000 m/s ([9]). Using this value, we can estimate that the time of the order of 10 ms is necessary to ignite the whole bed. If we compare this time with the time spans between attaining z = 0.02 and z = 0.5 (the range of z values corresponding to the ascending parts of $G(z)$ curves): 8 ms for $\Delta = 50$ kg/m^3, 10 ms for $\Delta = 100$ kg/m^3 and 5 ms for $\Delta = 150$ kg/m^3), we can conclude that the process of flame propagation along the bed may influence the shape of $G(z)$ curves.

Another explanation can be given basing on some peculiarities of the black powder ignition process described in [9]. It was observed that the flame spreading along a surface of a black powder grain is much slower than the flame spreading in a bed. It is much slower than the spreading of flame along the surface of smokeless powders grains. The flame spreads mainly due to the interaction of grains with the liquid products of the black powder burning (potassium salts, mainly K_2SO_4). They are ejected from the burning surface in the form of droplets of the size 1-10 μm [9]. Impinging on a surface of a grain, they cause a local ignition. Therefore, the grain does not start to burn on its whole surface. A time is necessary, to ignite the whole surface. During this time the burning surface increases, which is reflected in the shape of $G(z)$ curves.

Both explanations generate a problem with making use of the results, obtained on the basis of tests performed for black powder, to the conditions, when black powder acts as an igniter. In this case it is closed in a plastic bag and arranged around the igniting head. These conditions facilitate the ignition. However, after the bag bursting grains are dispersed inside the vessel. Therefore, the process of their combustion is different from that, when black powder is distributed in the form of a bed in the vessel.

In order to assess, if the vivacity function given by Eq. (13) can be used for predicting the changes of the pressure produced by the igniter, calculated and recorded pressure courses for 1 g and 2 g black powder igniters (146.5 cm^3 vessel) and for 3 g igniter (200 cm^3 vessel) are compared in Fig. 4. In the case of 1 g igniter the predicted pressure course is quite close to the recorded one. For 2 g igniter the prediction is worse, however the difference of the experimental and predicted values is not larger than the scatter of experimental data. But in the case of 3 g igniter there is a large difference between measured and predicted pressure courses.

This discrepancy between results of predictions and measurements illustrate the problem in predicting the course of pressure generated by the igniter. We cannot use the vivacity function, determined at the combustion of a distributed bed of black powder, in conditions differing from those, in which the function was determined. The problem is that the ascending part of the vivacity curve is not a material characteristic, but it reflects the process of ignition.

In further considerations we will use Eq. (13) for predicting the pressure pulse generated by the igniter, taking into account that this prediction is highly uncertain.

3.2. Real ignition pressure

Figure 5 presents the initial parts of pressure records obtained in closed vessel tests in which several propellants were ignited by 2 g of black powder. The capacity of the chamber was 200 cm^3 and the loading density of the propellants was 100 kg/m^3. The pressure course of the igniter is calculated by using the vivacity function given by Eq. (13). As it can be seen for all propellants the pressure grows faster than predicted for the burning of the igniter alone. Moreover, the pressure rise rate is different for various propellants. It indicates, without any doubts, that the propellants were ignited before attaining the nominal ignition pressure. It means that black powder burns at the same time as the tested propellant.

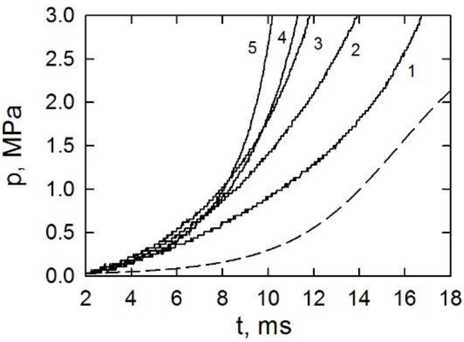

Fig. 5. Initial parts of the pressure records for combustion of propellants: 1 – 15/1 TR, 2 – 9/7, 3 – WT, 4 – 4/1, 5 – NPŁ 11-13 (solid lines) and the predicted pressure course for burning of 2 g of black powder alone (dashed line)

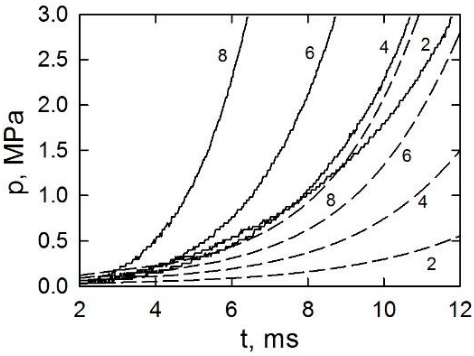

Fig. 6. Initial parts of the pressure records for combustion of WT propellant (solid lines) and the predicted pressure courses for burning of 2, 4, 6 and 8 g of black powder alone (dashed lines)

Figure 6 presents the initial parts of pressure records obtained in closed vessel tests for the combustion of WT propellant, which was ignited by the 2, 4, 6 and 8 g black powder igniters. The pressure rise is considerably faster than predicted.

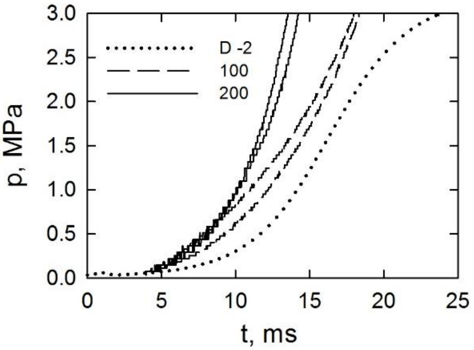

Fig. 7. Initial parts of the pressure records for combustion of LO5460(JA-2) propellant at the loading density values 100 and 200 kg/m^3 and the predicted pressure course for burning of 2 g of black powder alone (dotted line)

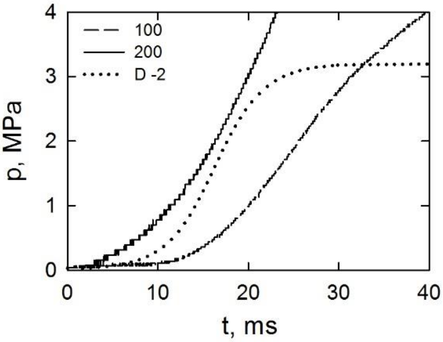

Fig. 8. Initial parts of the pressure records for combustion of SC propellant at the loading density values 100 and 200 kg/m^3 and the predicted pressure course for burning of 2 g of black powder alone (dotted line)

Figure 7 presents the initial parts of pressure courses obtained in closed vessel tests for the combustion of LO5460 (JA-2) propellant, which was ignited by the 2 g black powder igniter. Four tests were performed in 200 cm^3 capacity vessel: two for each value of the loading density. The pressure rise rate is larger than predicted. Moreover, the pressure rise rate depends on the loading density. This observation corroborates that the main charge starts to burn before complete burning of black powder.

The LOVA type propellants are difficult to ignite. Figure 8 illustrates this property. The pressure course for 100 kg/m^3 loading density shows considerably slower pressure rise rate than the predicted one for combustion of the igniter alone. Therefore, we can suppose that this course reflects burning of black powder. The tested propellant is probably ignited at the pressure value close to the nominal ignition pressure. The same conclusion can be drawn when we use the approach proposed in the Section 2.2, because the vivacity function of the tested propellant is calculated only when the predicted pressure of the products of combustion of black powder is lower than the measured value. However, in the case when the ignition of the tested propellant takes place at a pressure value much lower than the nominal ignition pressure (like for the loading density 200 kg/m^3), this approach underestimates the partial pressure of the tested propellant and the rate of pressure increase. It means that the calculated vivacity values are reliable only for pressure values higher than the nominal ignition pressure.

3.3. Vivacity functions

Figures 9-12 confront the vivacity functions determined at the assumption that the tested propellants are ignited at the nominal ignition pressure and determined using the proposed approach. Results obtained for WT propellant (Figs. 9 and 10) seems to be rational. Taking into account parallel combustion of black powder and tested propellant provides vivacity functions much closer to each other. It means that the assumption of the ignition at the nominal ignition pressure overestimates in this case the influence of the igniter on the vivacity function.

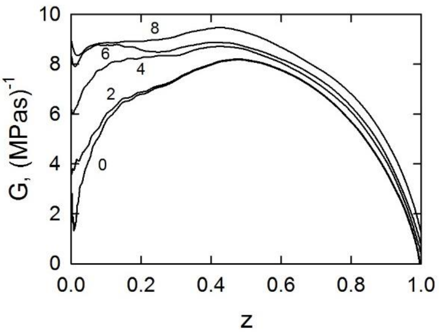

Fig. 9. Dynamic vivacity functions of WT propellant ignited by 0 (only ignition head), 2, 4, 6 and 8 g of black powder (nominal ignition pressure)

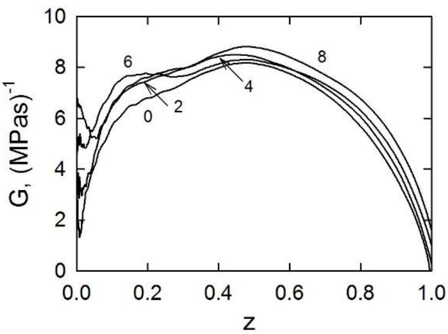

Fig. 10. Dynamic vivacity functions of WT propellant ignited by 0 (only ignition head), 2, 4, 6 and 8 g of black powder (predicted ignition pressure)

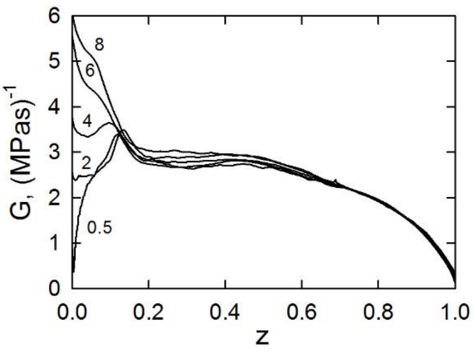

Fig. 11. Dynamic vivacity functions of 9/7 propellant ignited by 0.5, 2, 4, 6 and 8 g of black powder (nominal ignition pressure)

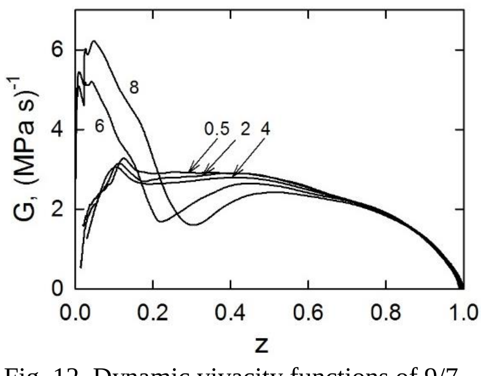

Fig. 12. Dynamic vivacity functions of 9/7 propellant ignited by 0.5, 2, 4, 6 and 8 g of black powder (predicted ignition pressure)

In the case of 9/7 propellant (Figs. 11 and 12) the vivacity functions obtained for 0.5, 2 and 4 g black powder igniters seems to be rational. But the vivacity functions determined for 6 and 8 g black powder igniters are evidently erroneous. We could expect that the initial peak would be reduced, while the further part would converge to the curves obtained for 0.5, 2 and 4 g igniters. The shape of vivacity functions for 6 ang 8 g do not agree with this expectation. We can conclude that the prediction underestimates the values of black powder partial pressure in the initial stage of the process and overestimates it in the further stage. Plots of time changes of the pressure derivative shown in Fig. 13 shed some light on a possible reason of this.

The initial parts of d*p*/d*t* courses have high increasing slope. But this trend stops at an inflexion or even a local maximum.

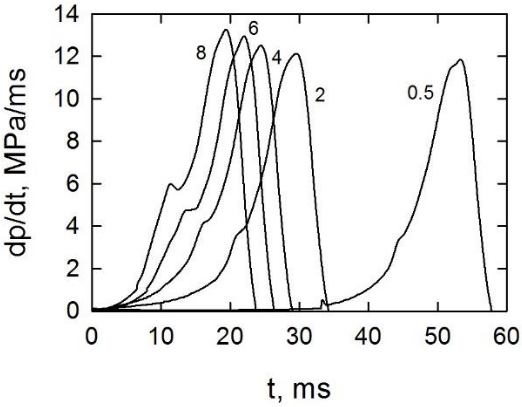

Fig. 13. Courses of the pressure time derivative for 9/7 propellant ignited by 0.5, 2, 4, 6 and 8 g of black powder

We can speculate that this part of the courses corresponds to the parallel combustion of black powder and tested propellant. The temperature of the flame of single-based and double-based propellants reaches respectively 2800-2900 K and 3500-3600 K [1], while the flame temperature of black powder 1500-1600 K [14]. Hot gases produced by combustion of smokeless powders accelerate burning of black powder grains. Moreover, they may accelerate the ignition of black powder grains, which were not ignited or ignited partially. In such a situation the vivacity function given by Eq. (13) is not adequate for prediction of the black powder partial pressure, because it corresponds to a relatively slow ignition of black powder grains.

The accelerated burning of black powder may also influence the combustion of the tested propellant, speeding up its ignition. We must also consider that there is a mixing of combustion products. The high temperature of smokeless powders combustion products may cause partial evaporation of liquid products of black powder combustion. On the other hand, this temperature may be diminished by the energy exchange.

All these factors cause that the process of the parallel burning of black powder and tested propellant is very complicated and very difficult for a theoretical description.

In [6] and [15] a dependence of the vivacity functions on the loading density was described and discussed. The initial heating of the external parts of grains before their ignition, causing an accelerated combustion, was suggested as a probable reason of this dependence. Results of investigations presented in this paper suggest that the process of parallel burning of black powder and tested propellants may also be responsible for this effect.

4. CONCLUSIONS

Results of the analysis presented in Sec. 3 lead to the following conclusions:

1. In closed vessel tests, carried out with the use of black powder igniters, the main charge is ignited at the values of pressure much lower than the nominal ignition pressure. Therefore, the main charge and black powder burn parallel. A coupling of the combustion of black powder and tested propellants complicates theoretical analysis of this process.
2. In the case of LOVA type propellants and low values of the loading density the ignition pressure may be close to the nominal value.
3. The vivacity function of black powder determined in closed vessel tests is not adequate to predict the partial pressure of black powder used as an igniter, because its large part reflects the ignition process. It would be desirable to determine the black powder vivacity function for conditions of very fast ignition of all grains, for example using explosion of a gaseous mixture.
4. Results of this work and the analysis of literature data show that the exponent in the burning law of black powder is close to 0.21 in the pressure range 0.5-200 MPa.

FUNDING

This work includes results of investigations carried out in the frame of the project financed by the Polish National Centre for Research and Development in 2016-2019 years. Project No. DOB-BIO8/05/01/2016.

REFERENCES

[1] Leciejewski Zbigniew. 2008. *Analysis and Estimation of the Correctness of the Testing Methods of Single and Double Based Propellants* (in Polish). Warsaw, Poland: Military University of Technology.

[2] Leciejewski Zbigniew. 2007. Singularities of Burning Rate Determination of Fine-Grained Propellants. In *Proceedings of the 23rd International Symposium on Ballistics* 1 : 369-376. 16-20 April, 2007, Tarragona, Spain.

[3] Price C., Juhasz A. 1977. *A Versatile User-oriented Closed Bomb Reduction Data Program*. BRL Report 2018, U.S. Army Ballistic Research Laboratory, Aberdeen Proving Ground, MD, USA.

[4] Papliński Andrzej, Zbigniew Surma, Andrzej Dębski. 2009. "Theoretical and Experimental Analysis of Ballistic Properties of Black Powder" (in Polish). *Materiały Wysokoenergetyczne – High Energy Materials* 1: 89-94.

[5] Serebryakov M. 1949. *Internal Ballistics* (in Russian). Moscow: Oborongiz.

[6] Trębiński Radosław, Zbigniew Leciejewski, Zbigniew Surma, Bartosz Fikus. 2016. Some considerations on the methods of analysis of closed vessel test data. In *Proceedings of the 29th International Symposium on Ballistics* 1 : 607-617. 9-13 May 2016, Edinburgh, Great Britain.

[7] Sasse R.A. 1983 *Strand Burn Rates of Black Powder to One Hundred Atmospheres*. Technical Report ARBRL-TR-02490, May 1983.

[8] Konecny Pavel, Z. Křižan. 2008. „Determination of Black Powder Burning Rate". *Advances in Military Technology* 3 (2) : 11-18.

[9] Williams F.A. 1976 "Observations on Burning and Flame-Spread of Black Powder". *AIAA J*. 14 (5) : 637-645.

[10] Glazkova A.P., I.A. Tereshkin. 1961. "On the Dependence of the Burning Rate of Explosives on Pressure (in Russian)". *Zhurn. Phys. Khimii,* 35 (7) : 1622-1629.

[11] Sasse R.A. 1981. *The Influence of Physical Properties on Black Powder Combustion.* Technical Report ARBRL-TR-02308, March 1981.

[12] Belayev A.F., A.I. Korotkov, A.K. Parfenov, A.A. Sulimov. 1963. "The Burning Rate of Some Explosive Substances and Mixtures at Very High Pressures (in Russian)". *Zhurn. Phys. Khimii* 37 (1) : 150-156.

[13] Kosanke K.L., B.J. Kosanke. 2003. "Pyrotechnic Burn Rate Measurements: Interstitial Flame Spread Rate Testing". *American Fireworks News* 257 : 664-669.

[14] Brown M.E., R.A. Rugunanan. 1989. "A Temperature-Profile Study of the Combustion of Black Powder and its Constituent Binary Mixtures". *Propellants, Explosives, Pyrotechnics* 14: 69-75.

[15] Trębiński Radosław, Zbigniew Leciejewski, Zbigniew Surma, Bartosz Fikus. 2017. Analysis of Dynamic Vivacity Curves Obtained on the Basis of Valved Closed Vessel Test Data. In *Proceedings of the 30th International Symposium on Ballistics* 1 : 496-504. 11-15 September, 2017, Long Beach, CA, USA.

Badania wpływu zapłonu na krzywe dynamicznej żywości prochów

Radosław TRĘBIŃSKI, Zbigniew LECIEJEWSKI, Zbigniew SURMA

Wojskowa Akademia Techniczna im. Jarosława Dąbrowskiego,
Wydział mechatroniki i Lotnictwa
ul. gen. Sylwestra Kaliskiego 2, 00-908 Warszawa

Streszczenie: W pracy opisano próbę określania funkcji dynamicznej żywości prochów przy uwzględnieniu równoległego spalania zapłonnika z prochu czarnego i badanego prochu. Podejście jest oparte na prezentowanych wynikach prób pirostatycznych, dowodzących, że spalanie badanego prochu zaczyna się przed całkowitym spaleniem prochu czarnego. Opierając się na wynikach testów pirostatycznych dla prochu czarnego, określono jego funkcję dynamicznej żywości. Została ona wykorzystana do predykcji cząstkowego ciśnienia produktów spalania prochu czarnego w przypadku, gdy proch czarny został użyty jako zapłonnik. Krzywe dynamicznej żywości porównano z krzywymi dynamicznej żywości obliczonymi przy założeniu, że spalanie głównego ładunku zaczyna się po pełnym spaleniu prochu czarnego. Otrzymane rezultaty pokazały, że rozpatrywany sposób podejścia zawodzi ze względu na skomplikowany charakter oddziaływania pomiędzy zapłonnikiem i badanym prochem.

Słowa kluczowe: balistyka wewnętrzna, dynamiczna żywość, zapłon