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EVALUATION OF SURFACE MODIFICATION OF SMOKELESS POWDER GRAIN BY BALLISTIC EFFICIENCY PARAMETER

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Four series of model powder samples for propelling charges were tested in terms of the ability of burning modifiers to affect burning progressiveness. The experiments showed that various substances have different abilities to affect this parameter. Energetic efficiencies were compared in real set-up of ammunition 9x19 mm with the results of parallel testing of powders in closed ballistic bomb. Real possibilities of application of this finding in the process of development of real powders for propelling charges are discussed.

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Introduction

Within the research of the conditions influencing the burning progressiveness, the effect was studied of feeding mode of various modifiers (separate or combined) on smokeless powder grain surface. For this purpose four different model series were tested, prepared of two powder matrices differing in the material density. The doses of modifiers were balanced by calculation to roughly equal starting energetic state of all samples in the model series. Energetic efficiency of ballistic process was evaluated using the modified method according to Riefer [1] at the temperatures of –54 °C, +21 °C and +52 °C. The powder properties were evaluated in closed ballistic bomb according to MIL-STD-286C [2] procedures.

According to [1] energetic efficiency e_{MVEL} is given by equation

$$e_{MVEL} = \frac{E_x}{E_{MVEL}} 100 \tag{1}$$

where E_x is the measured bullet kinetic energy and E_{MVEL} is ideal bullet muzzle kinetic energy.

For the expansion ratio K lower than 1 the ideal energy E_{MVEL} is given by

$$E_{MVEL} = \frac{f\omega}{(k-1)\left(1+\frac{\omega}{3w}\right)} - \frac{p_0\left(V_0+Dx_2-\eta\omega\right)}{(k-1)\left(1+\frac{\omega}{2w}\right)} K^k \tag{2}$$

In the case the powder burns out after the bullet has left the barrel the expansion ratio K is higher than 1. In this case Eq. (2) is incorrect, the correct equation being as follows

$$E_{MVEL} = \frac{p_0 Dx_2}{1+\frac{\omega}{2w}} \tag{3}$$

Ideal muzzle bullet velocity v_{MVEL} is similarly given by

$$v_{MVEL} = \sqrt{\frac{2E_{MVEL}}{w}} \tag{4}$$

Then the experimentally achieved percentage of ideal velocity v_{PC} is given by

$$v_{PCL} = \frac{v_x}{v_{MVEL}} 100 = \sqrt{100 e_{MVEL}} \qquad (5)$$

The symbols used in equations are: D – barrel diameter [m], h – covolume [m^3 kg^{-1}], ω – weight of powder charge [kg], E_{MVEL} – ideal bullet muzzle kinetic energy [J], e_{MVEL} – energetic efficiency [%], v_{PC} – velocity efficiency [%], f – powder force [$J.kg^{-1}$], k – gas expansion constant, K – expansion ratio, P – mean gun pressure [MPa], v_x 2 measured bullet velocity [m s^{-1}], E_x – measured bullet kinetic energy [J], x – bullet trajectory in barrel [m].

Basic assessment was accomplished also by means of the closed ballistic bomb test using the procedure according to [1] as the evaluation of powder vivacity and emission function Γ (relative quickness) excluding heat losses. Mean emission function $\Gamma\phi$ is defined by

$$\Gamma\phi = \frac{1}{1 - 2KZ} \int_{KZ}^{1-KZ} [\Gamma]_{P/P_{max}} d(P/P_{max}) \qquad (6)$$

where KZ is optional relative ordinate at ignition termination; P – actual pressure, P_{max} – maximal pressure.

Results

Basic information about model samples is summarized in Table I. Calculated energetic and velocity efficiencies of model samples are summarized in Table II. Energetic efficiencies of ballistic process for individual modifiers as a function of temperature are presented in Figs 1-4 in comparison with original powder matrix. The results of tests in closed ballistic bomb are summarized in Table III.

Table I Basic parameters of model powder samples calculated by software TCHAR [3]

Sample (series)	modifier (compound, %)	f kJ kg^{-1}	κ	$h \times 10^3$ m^3 kg^{-1}	Q_E (H_2O liq.) kJ kg^{-1}
XS020-0/8 (I)	no modif.	1,030.1	1.2289	1.1829	3,937
XS020-6/8 (I)	NG/15	1,092.6	1.2190	1.1339	4,396
XS020-9/8 (I)	NG/15 + CII	1,079.9	1.2233	1.1531	4,254
XS020-10/8 (I)	NG/15 + AcII	1,079.5	1.2230	1.1527	4,254
XS020-13/8 (I)	NG/15 + CI	1,079.2	1.2233	1.1540	4,248
XS020-14/8 (I)	NG/15 + DNT	1,081.6	1.2239	1.1554	4,243
XS020-0/27 (II)	no modif.	1,030.0	1.2289	1.1830	3,937
XS020-1/27 (II)	NG/15	1,051.7	1.2256	1.1662	4,09
XS020-4/27 (II)	NG/15 + CI	1,079.2	1.2233	1.1541	4,248

Table I – Continued

Sample (series)	modifier (compound, %)	f kJ kg^{-1}	κ	$h\times10^3$ m^3 kg^{-1}	Q_E (H_2O liq.) kJ kg^{-1}
XS020-5/27 (II)	NG/15 + CII	1,079.8	1.2231	1.1531	4,254
XS020-6/27 (II)	NG/15 + AcII	1,079.5	1.2231	1.1527	4,253
XS020-7/27 (II)	NG/15 + DNT	1,081.5	1.2239	1.1555	4,243
XS020-15/8 (III)	CI	1,022.1	1.2311	1.1936	3,863
XS020-16/8 (III)	CII	1,025.5	1.2310	1.1931	3,866
XS020-17/8 (III)	AcII	1,022.2	1.2309	1.1926	3,866
XS020-18/8 (III)	DNT	1,023.2	1.2313	1.1943	3,861
XS020-19/8 (III)	BuNENA	1,050.7	1.2249	1.1625	4,049
XS020-20/8 (III)	DNDA	1,028.4	1.2323	1.2007	3,865
XS020-21/8 (IV)	CI	1,026.1	1.2300	1.1883	3,9
XS020-22/8 (IV)	CII	1,026.2	1.2299	1.1879	3,901
XS020-23/8 (IV)	AcII	1,026.3	1.2299	1.1880	3,901
XS020-24/8 (IV)	DNT	1,022.4	1.2310	1.1932	3,857

Table II Relation of energetic and velocity efficiency of ballistic process e_{MVEL} and v_{PC} for individual modifiers

Sample (series)	Modifier (compound, %)	e_{MVEL}			v_{PC}		
		−54 °C %	+21 °C %	+52 °C %	−54 °C %	+21 °C %	+52 °C %
XS020-0/8 (I)	no modif.	78.6	85.3	80.2	88.7	92.4	89.6
XS020-6/8 (I)	NG/15	83.0	84.7	87.4	91.1	92.1	93.5
XS020-9/8 (I)	NG/15 + CII	84.3	84.9	83.7	91.8	92.2	91.5
XS020-10/8 (I)	NG/15 + AcII	85.1	85.2	82.3	92.2	92.3	90.7
XS020-13/8 (I)	NG/15 + CI	84.6	84.6	83.3	92.0	92.0	91.3
XS020-14/8 (I)	NG/15 + DNT	84.3	84.0	81.6	91.8	91.7	90.3
XS020-0/27 (II)	no modif.	68.4	79.0	79.0	82.7	88.9	88.9
XS020-1/27 (II)	NG/15	79.7	81.2	77.9	89.3	90.1	88.3
XS020-4/27 (II)	NG/15 + CI	77.4	77.0	74.1	88.0	87.8	86.1
XS020-5/27 (II)	NG/15 + CII	80.0	77.3	75.3	89.4	87.9	86.8
XS020-6/27 (II)	NG/15 + AcII	78.5	77.2	75.1	88.6	87.9	86.7
XS020-7/27 (II)	NG/15 + DNT	79.5	74.2	71.0	89.2	86.1	84.3
XS020-15/8 (III)	CI	88.3	91.6	93.1	93.9	95.7	96.5
XS020-16/8 (III)	CII	76.2	84.4	85.7	87.3	91.9	92.6
XS020-17/8 (III)	AcII	81.4	82.7	87.5	90.2	90.9	93.5
XS020-18/8 (III)	DNT	79.4	84.8	86.9	89.1	92.1	93.2
XS020-19/8 (III)	BuNENA	77.1	80.1	82.7	87.8	89.5	90.9
XS020-20/8 (III)	DNDA	74.5	82.6	83.6	86.3	90.9	91.5
XS020-21/8 (IV)	CI	75.6	84.9	85.8	87.0	92.1	92.6
XS020-22/8 (IV)	CII	73.9	84.2	85.8	85.9	91.8	92.6
XS020-23/8 (IV)	AcII	77.6	89.3	91.1	88.1	94.5	95.4
XS020-24/8 (IV)	DNT	71.4	83.7	84.5	84.5	91.5	91.9

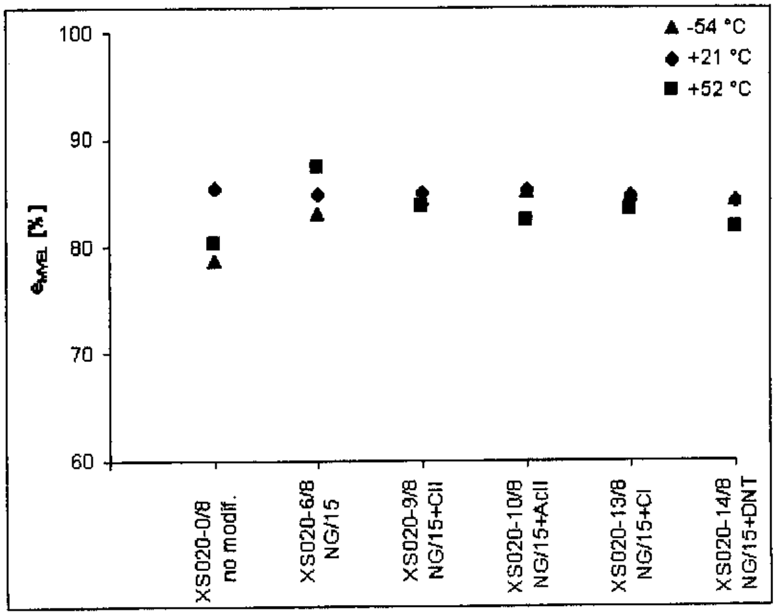

Fig. 1 Energetic efficiency of ballistic process e_{MVEL} for individual modifiers – series I

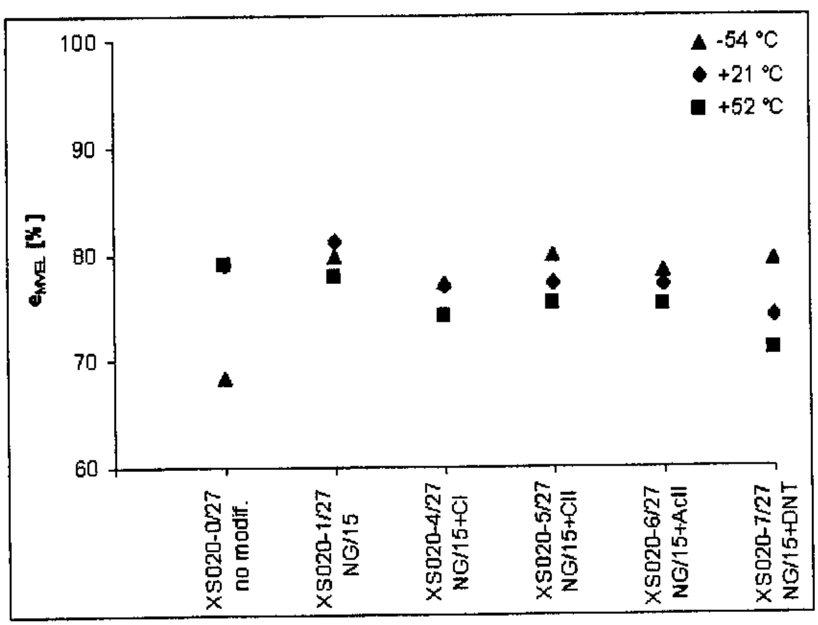

Fig. 2 Energetic efficiency of ballistic process e_{MVEL} for individual modifiers – series II

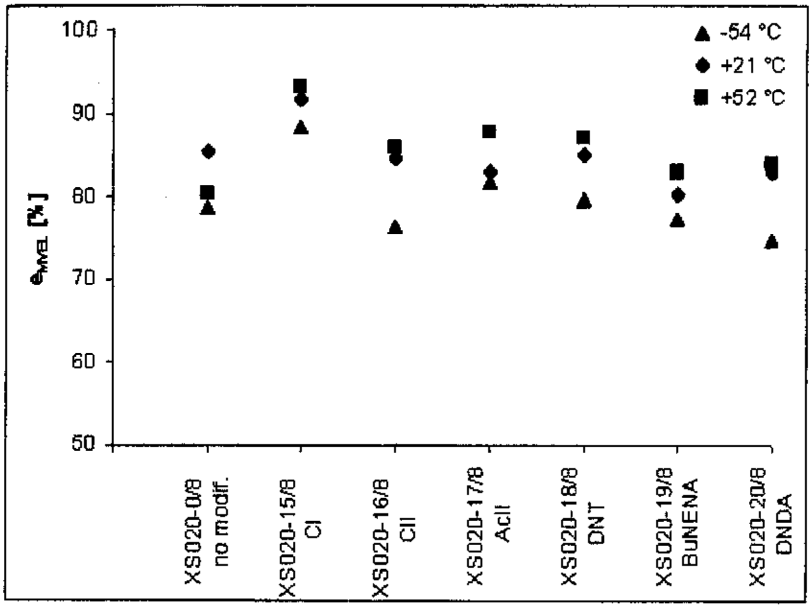

Fig. 3 Energetic efficiency of ballistic process e_{MVEL} for individual modifiers – series III

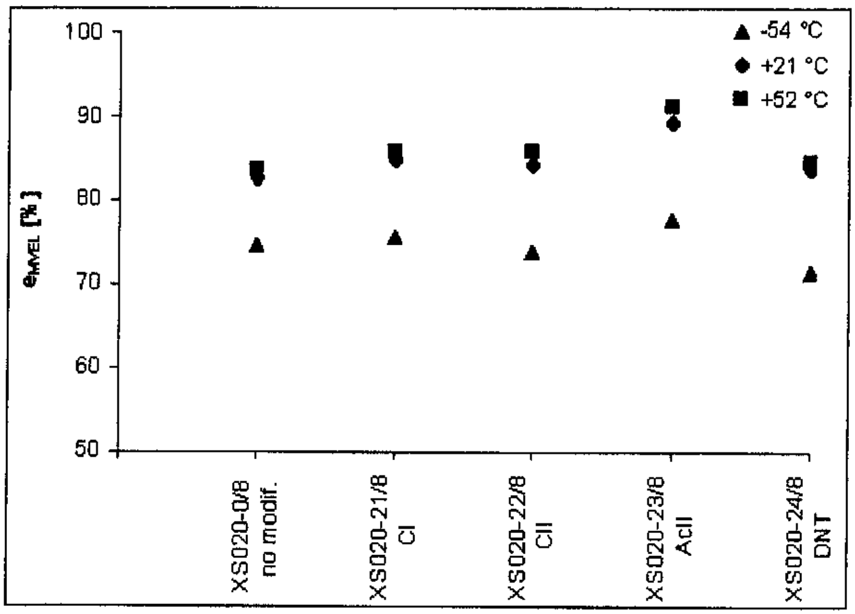

Fig. 4 Energetic efficiency of ballistic process e_{MVEL} for individual modifiers – series IV

Table III Results of comparison in closed ballistic bomb

Sample (series)	Modifier (compound, %)	P_{max} MPa	Impulse Mpa ms	$(dP/dT)_{max}$ Mpa ms^{-1}	$(dP/dT)_{avg}$ Mpa ms^{-1}	$GAMMA_{max}$ MPa^{-1} s^{-1}	$GAMMA_{avg}$ MPa^{-1} s^{-1}
XS020-0/8 (I)	no modif.	226.3	50.8	672.5	548.0	26.8	25.0
XS020-6/8 (I)	NG/15	236.6	42.0	786.3	669.8	40.5	27.8
XS020-9/8 (I)	NG/15 + CII	235.0	45.5	739.8	614.7	34.2	26.0
XS020-10/8 (I)	NG/15 + AcII	234.6	48.1	801.8	590.9	29.6	25.1
XS020-13/8 (I)	NG/15 + CI	236.3	52.4	618.0	542.9	25.8	22.6
XS020-14/8 (I)	NG/15 + DNT	236.8	52.2	665.9	554.5	26.7	23.1
XS020-0/27 (II)	no modif.	228.8	63.6	538.7	446.8	22.5	20.1
XS020-1/27 (II)	NG/15	236.3	53.9	567.0	506.7	34.1	20.9
XS020-4/27 (II)	NG/15 + CI	233.7	60.1	528.4	455.8	22.8	19.3
XS020-5/27 (II)	NG/15 + CII	234.9	54.8	592.8	493.0	27.3	20.8
XS020-6/27 (II)	NG/15 + AcII	235.5	58.2	601.8	486.1	23.6	20.3
XS020-7/27 (II)	NG/15 + DNT	234.0	63.2	38747	436.6	21.2	18.5
XS020-15/8 (III)	CI	221.2	48.7	676.3	550.5	28.2	26.3
XS020-16/8 (III)	CII	221.8	47.8	689.7	559.9	28.5	26.6
XS020-17/8 (III)	AcII	224.0	46.8	703.8	576.0	28.9	26.9
XS020-18/8 (III)	DNT	221.5	50.9	674.0	541.5	27.5	25.8
XS020-19/8 (III)	BuNENA	222.9	52.1	666.0	38742	27.0	25.3
XS020-20/8 (III)	DNDA	223.6	51.8	677.7	553.0	27.6	25.8
XS020-21/8 (IV)	CI	223.1	47.5	689.8	561.6	28.2	26.4
XS020-22/8 (IV)	CII	223.1	47.2	681.0	555.4	27.9	26.1
XS020-23/8 (IV)	AcII	223.5	46.7	686.2	562.8	28.3	26.4
XS020-24/8 (IV)	DNT	221.5	52.9	652.5	532.7	27.1	25.3

Conclusion

The ability of used modifier or combination of modifiers to change the efficiency of ballistic process was studied in this paper. The influence of density (samples /8 are more porous then /27) and concentration of modifier (series IV contains half concentration of modifier than series III) is also important. Generally, combined modification is more effective than modification with a single compound. The closed ballistic bomb seems to be less useful for exact evaluation.

Acknowledgements

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References

[1] Riefler D.V.: Inner ballistic efficiency of barrel weapons, Handy Road Hamden Connecticut 06518, U.S.A., 1995

[2] MIL-STD-286B, Determination of burning rate and force of powder in closed bomb, method 801.1.2
[3] Bauer I., Zigmund J.: Software TCHAR EXPERT, VÚPCH Pardubice, 1999.

Abbreviations

AcII	Acardite II	f	powder force
avg.	average	h	covolume
BuNENA	*N*-n-butyl-*N*-(2-nitroxy ethyl)nitramine	κ	ratio of specific heats
CI	Centralite I	*max.*	maximal
CII	Centralite II	NG	nitroglycerin
DNDA	linear nitramines	P	pressure
DNT	2,4-dinitrotoluene	Q_E	heat of explosion