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GUN BARREL EROSION – COMPARISON OF CONVENTIONAL AND LOVA GUN PROPELLANTS

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ABSTRACT

Our research group is involved in the development and (safety and IM) testing of conventional (NC based) and TPE based gun propellants. The latter has been developed in a CEPA 14 cooperation program.

Recently our testing capabilities have been extended with gun barrel erosion tests in order to find out whether new developed (LOVA) gun propellants or propellant formulations perform better in erosion tests. At the moment we have two vented vessels tests available, making it possible to determine the extent of erosion from a relatively low lading density to one comparable to a large caliber gun (maximum allowable pressures from 20 to 400 MPa).

Test pieces of various materials have been used.

A number of LOVA and conventional gun propellants have been tested.

The results of these experimental setups have been compared as are the rankings obtained. The erosion dependency on propellant properties like flame temperature and combustion gas composition has been determined.

In this paper the experimental and theoretical results are described and compared as are the insight obtained in erosion mechanisms and scaling.

Furthermore, an internal ballistics code has been adapted to model the pressure and temperature development in a vented vessel. The results are compared with the experimental results. This model will be described in short and the results presented.

1. INTRODUCTION: EROSION AND WEAR LIFE

Gun barrel erosion is a phenomenon caused by the action of the fast flow of hot corrosive gasses and the mechanical action of the projectile. Heat transfer to the barrel wall is a very important factor and therefore the temperature of the gasses, the flame temperature [1, 5] plays an important role. For this reason an important drive in the propellant development is to find formulations with a high impetus but low flame temperature. However, these entities are interrelated.

In shooting a combined attack of hot, oxidative gasses and mechanical friction of the projectile takes place at the barrel inner surface (see figure 1).

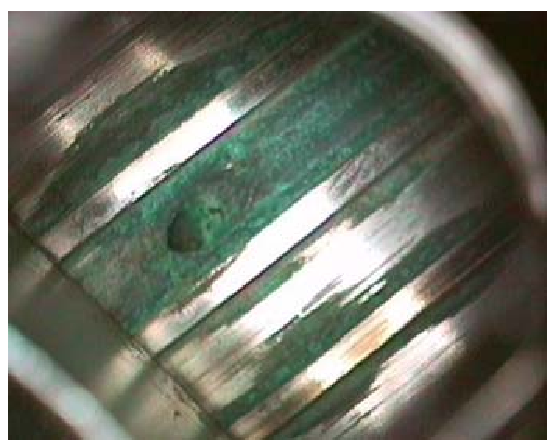

Figure 1 Erosion of rifling grooves.

For a barrel with rifling grooves it is observed that at the origin of rifling the damage is at the largest, going through a minimum and to increase again at the muzzle (see figure 2 [1]).

Smooth barrels are usually coated or Chromium plated; in shooting the coating is attacked and damaged. It is observed that after a number of shots the number of damaged spots show no increase, but the area per spot does increase.

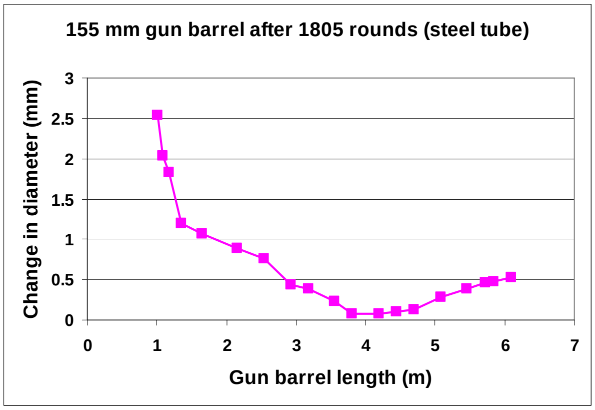

Figure 2 Erosion along the tube length starting at the Origin of rifling [1].

To be able to predict the effect of changes in the formulation or changes in the gun barrel material erosion tests were developed.

The work of De Vieille [2] reported in 1910 is very fundamental. His experiments with various test piece materials ranging from Platinum to Zinc, thus comprising a large melting temperature range, are very interesting. These demonstrate the importance of heat transport by the gasses to the inner surface and from there to the bulk of the tube by heat conductivity.

A lot of work, experimental and theoretical has been performed on the effect of propellant properties [3, 4, 8]. To be mentioned are the flame temperature and the hot gas composition: the CO/CO_2 ratio and the amount of nitrogen formed, important for the formation of respectively oxides/carbides and nitrides.
The effect of propellant mass in erosion tests shows the importance of heat transport; when the energy available and the heat transport are both insufficient to reach the melting point of the test material, no mass loss of the test piece occurs. However, above this critical propellant mass, the erosion (mass loss) of the test piece is linear with the propellant mass [7]

The code TIBALCO-vent has been developed to simulate the pressure time curve for a vented vessel, in order to be able to predict maximum pressure values as a safety measure.

2. NOMENCLATURE

A_T	: erosivity based on T_f	(K^{-1})
CV	: Closed vessel	
HPCV	: high pressure CV	
LPCV	: low pressure CV	
LOVA	: LOw VulnerAbility	
NC	: NitroCellulose	
T_f	: flame temperature	(K)
I	: Impetus	(J/g)
α	: burning rate exponent	(-)
β	: pre exponent number	
r	: burning rate	(m/s)
R	: RDX, a high explosive	
TPE: thermoplastic elastomer		
ETPE	: energetic TPE	

3. EROSION TESTS

3.1 Test setups

There are a number of possible erosion test set ups, ranging from vented vessels to actual gun tubes. In this way the test results will be governed by thermochemical to thermomechanical mechanisms for the full test scale. But, given a set up, there are three combinations possible:

Propellant type	Prop mass	Test piece material	remarks
Different	Con-stant	the same	Effect propellant proper-ties: flame temperature and gas composition
Constant	Con-stant	varying	Effect of heat transport, conductivity [2]
Constant	Vary-ing	the same	Optimization of test setup, effect length and diameter test piece. Effect of prop. mass

Table 1 Overview of possible combinations

Two types of vented vessels were developed, the Low Pressure one (LPCV) operating at pressures lower than 20 MPa and the High Pressure one (HPCV). (see figures 3 and 4)

Figure 3 Low pressure vented vessel

The LPCV is suited for small loading densities with low maximum pressures and may be used for the ranking of propellants from the view point of erosivity. The HPCV is suited for high loading densities with a design pressure of maximal 1000 MPa (HPCV). In this stage of the program the maximum allowable pressure was 150 MPa for the vented vessel. The test piece is followed by a restriction to prevent the flow to become supersonic within the test piece.

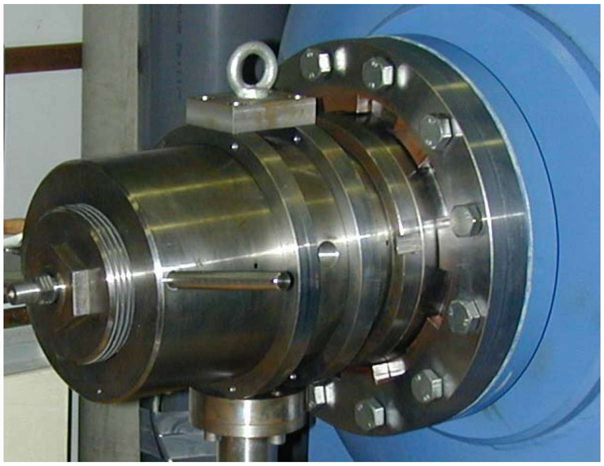

Figure 4 Vented high pressure closed vessel (HPCV)

3.2 Propellants tested

A number of propellants have been tested; LOVA and conventional ones. Conventional gun propellants show relatively inferior thermal behaviour and composite propellants have been developed to improve this behaviour with respect to cook-off and are therefore named LOVA (low vulnerability) propellants (see table 1 for some additional information)

Lawton [5] suggested two numbers to describe the propellant erosivity; one based on the flame temperature (A_t) and one based on the gas composition ((A_g). The relevant data of the propellants and the A_t number are presented in table 2.

	Conventional	LOVA propellants
Type	Homogeneous	Heterogeneous (composite propellants)
Basis	on nitrocellulose (NC) with energetic plasticiser (NGl)	- HTPB a curable binder - CAB (cellulose binder) - ThermoPlastic Elastomers (TPE)
Gas comp. CO/CO_2 H_2/H_2O	 3 - 9 0.4 – 1.4	 35 4
IM tests	Rel. inferior thermal behaviour	detonating behaviour need to be attended to
LOVA		improved response to foreign impulses

Table 1 Some information on propellants.

4. VENTED TEST RESULTS

4.1 The Vented LPCV

The tests in the Vented LPCV were carried out with two propellant configurations: one with the grain (either 7 or 19 perf grains) and with samples directly taken form a capillary rheometer cut in pieces of 1 cm each (cylinders with a diameter of about 0.15 cm) [10]. The masses used were resp. 2.80 and 2.30 gram of propellant giving about the same pressure. The tests were performed in duplicate and the mean spreading in the mass loss of the PMMA test pieces is about ± 7 %. The results are presented in table 3.

The data form table 3 is presented in figure 5 as well, showing that the mean mass losses fit reasonably well with an exponential relation with the flame temperatures. This relation shows a less vivid dependency on flame temperature than found in literature for higher loading densities, which is probably due to increased heat losses due to the small loading densities.

Furthermore, it appears that the NC and TPE /RDX based formulations show a somewhat different erosive behaviour.

Additional experiments are needed to elucidate the possible differences.

However, Caveny [7] has already demonstrated that RDX containing formulations are more erosive than NC based ones at a comparable flame temperature and impetus.

The ignition delay of LOVA propellants may be a problem: one needs a more powerful ignition for the RDX based propellants. In the experiments presented here some additional grains of igniter mass were added.

	Prop.	Imp. (J/g)	T_f (K)	Ballistic properties α	β (*10^3)
NC based					
single base	RB 107	923	2508	0.78	1.94
double base (tank)	I 5790	1085	3099	0.73	3.67
triple base	M 30	1065	3040	0.70	3.35
DB 2		1099	3149	0.92	1.40
DB 3		1120	3269	0.90	1.95
LOVA prop. (RDX based)					
LOVA 1	TPE /R	1046	2560	1.34	0.109
LOVA 2	TPE/R	1028	2472	1.29	0.108
LOVA 3	TPE /R	1027	2477	1.26	0.116
LOVA 4	ETPE/R	1178	2993	1.01	6.21
LOVA 5	TPE/R	1003	2292	1.26	0.111

Table 2 Some data of the propellants tested.

The erosion tests, especially the Vented LPCV, showed to be helpful in ranking the propellants in view of their erosivity.

4.2 The vented HPCV

Some preliminary tests have been performed with the Vented HPCV using the SB propellant RB 107 as a reference and a 34CrNiMo 6 test piece. It appeared that for 60 grams of RB 107 no weight loss of the test piece was observed, so we tested additionally 70, 80 and 90 grams of the reference propellant see figure 6) [10].

	Prop. erosivity A_t	LPCV mass loss (mg)		HPCV mass loss (mg)		
Mat. test piece		PMMA		CrNiMo		
Mass prop.(g)		2.8	2.3	90	80	70
Prop. shape		Gr.	cyl.	Gr.	Gr.	Gr.
Refer. prop.						
SB	123.8	62		825	388	1
DB (tank)	45.7	96				
TB	54.5	82				
DB 2	42.5		87			
DB 3	35.8		98			
LOVA prop.						
LOVA 1	123.8	59				
LOVA 2	129.4					
LOVA 3	128.2		38			
LOVA 4	53.7	106		2000		
LOVA 5	183.2		42			

Table3 Erosivity data and erosion test results

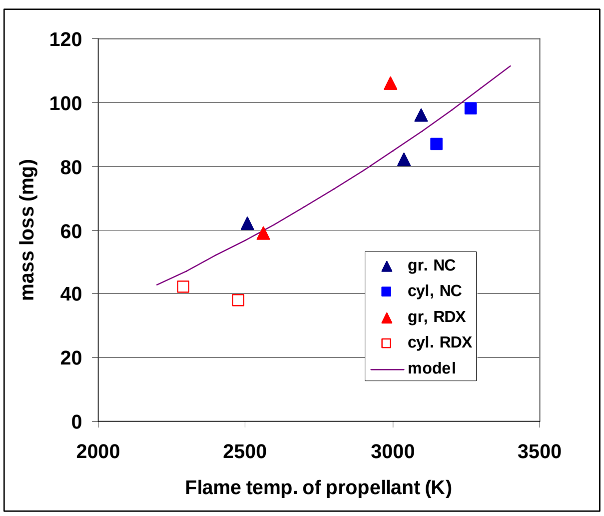

Fig. 5 Results of LPCV vented vessel tests performed with the propellants mentioned in table 1.

However, 90 grams of the more energetic EPTE /RDX formulation proved to be too much for the set-up, and some repair is needed. Additional experiments need to be carried out.
In figure 6 the results of different masses of a single base propellant are presented.

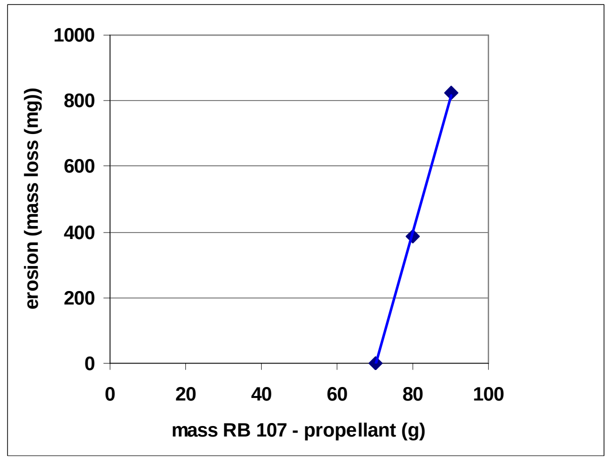

Fig. 6 Vented HPCV results with a SB propellant

5. MODELING: TIBALCO-VENT

TIBALCO stands for TNO Internal BALlistic COde [10] and resembles the IBHVG code, but is more flexible. With this code a pressure-time curve is calculated in several thousand time steps with the propellant burning characteristics and form function as input. A special module has been set up to calculate the isothermal gas release per time step.
However, in the lower pressure regime (< 22 MPa), the nitramine burning follows another rate exponent than in the higher pressure regimes. So, these have been determined first.
Another problem is heat loss: it is well known that in a gun the heat losses are about 2 % and in a closed vessel up to 10%. In the LPCV with a loading density of 0.02 (compared to 0.2 in a CV test), the heat losses appeared to be much higher, up to 40 %.
The erosion tests of RB 107 have been used as a reference. The use of the other propellants with a higher performance have been simulated before carrying out the tests in order to have an idea about the maximum pressure which could be reached.
In the figure 7 and 8 the experimental and simulated results of RB 107 (SB propellant) and of ETPE /RDX (a LOVA propellant) respectively have been presented.

It is concluded that the simulated curves agree rather well with the experimental ones.

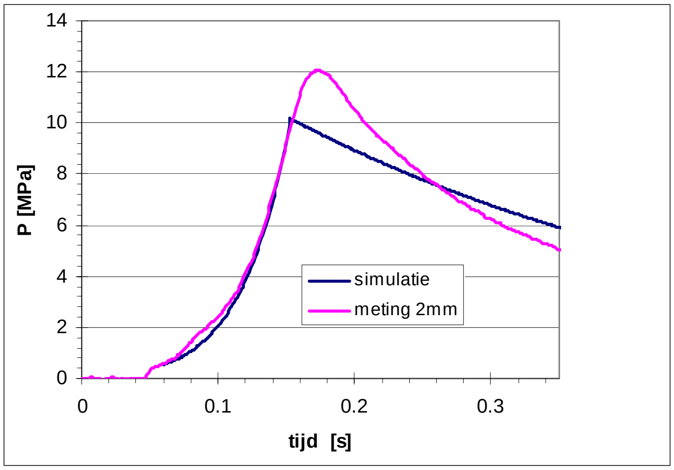

Fig. 7 Comparison of experimental (pink) and simulated (blue) results of RB 107

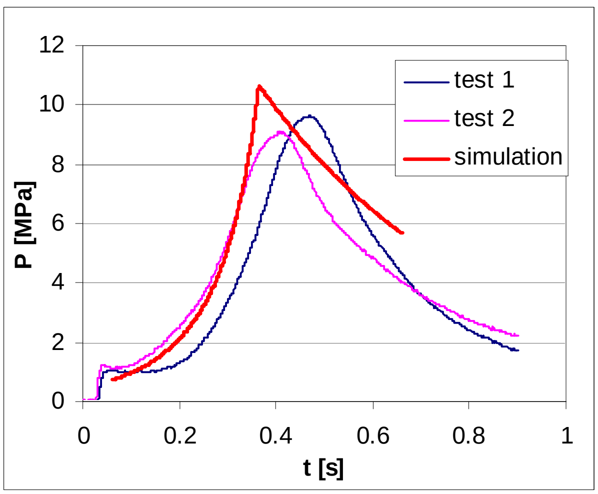

Fig. 8 Comparison of experimental (pink + blue) and simulated (red) results of ETPE / RDX formulation

6. CONCLUSIONS

The following conclusions can be drawn.

- The erosion tests, especially the Vented LPCV, showed to be very helpful in ranking the propellants in view of their erosivity.
- Small differences were found between NC based and TPE/RDX based formulations.
- The flame temperature dependency in LPCV testing is somewhat different from literature which is probably caused by increased heat losses.
- Preliminary tests with the vented HPCV showed a linear dependency on mass when a higher than a critical mass is used.
- The pressure – time curves simulated with TIBALCO-vent agree rather well with the experimental ones.

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