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PROPELLANTS AND PROPELLANT EROSIVITY

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The requirements for modern gun propellants are an improved performance (higher impetus, lower flame temperature), less erosivity, better LOVA or IM properties, and proper combustion behaviour and ageing characteristics.
Starting from formulation work TNO uses for ballistic and erosive testing a number of closed and vented vessels with a range in capacities and ignition sources.

In this paper an overview is given of TNO's work on propellant erosivity. The extent of erosion has been studied using various propellants and test orifice materials. First of all, only thermal effects have been studied at low loading densities, using polymer test orifice materials.
At higher loading densities, using gun steel and St 37 test orifice items, differences in erosion behaviour between LOVA and conventional gun propellants have been studied.
The heat input for the various test set-ups and guns are compared. The erosion effect of mass variations in both low and high pressure vented vessels resulted in linear, but different dependencies on propellant mass including a critical propellant mass at which erosion starts.

Erosion test results will be presented, including the heat transfer from the propellant gases to vessels with different capacities and to the venting orifice.

INTRODUCTION

Gun barrel erosion is a phenomenon caused by the action of the fast flow of hot corrosive gases, the thermal shock of the barrel and the mechanical action of the projectile [1-3]. Heat transfer to the barrel wall is a very important factor and therefore the temperature of the gases, the flame temperature [1,4], 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 characteristics are interrelated.
To be able to predict the effect of changes in the formulation or changes in the gun barrel material on gun barrel erosion, vented vessel tests were developed.
As early as 1901 De Vieille [5] started experiments with various test piece materials. Both experimental and theoretical work has been performed on the effect of propellant properties [6,7,10]. 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 [7,8]. And of course hydrogen gas [6]. Lawton [3] has clearly demonstrated that the erosive effect as determined with vented vessel tests is at least a factor 10 larger than found from gun firing data.

EROSION TESTS

Experimental setup

The Low Pressure Closed Vessel (LPCV) operating at pressures lower than 20 MPa and the High Pressure Closed Vessel (HPCV) to be used to pressures up to 150 MPa, were developed. The erosion test pieces have a cylindrical vent opening and are designed as to prevent the flow to become supersonic within the test piece. In the LPCV and HPCV various test materials have been used, from polymers (PMMA and Rulon) in the LPCV to Steel 37 (ASTM A284, grade C) and CrNiMo steel (which is comparable to gun steel) in the HPCV. In Table 1 the dimensions of the test pieces and in table 2 some properties of the test material are given (LD = loading density).

Table 1 Various test materials and vent hole sizes

	Test material	d (mm)	Length (mm)	for LDs (g/cc)
LPCV	PMMA	2	16	0.02
P_m = 20 MPa	Rulon	2	16	0.02
HPCV	34NiCrMo6	5	40	0.2
P_m = 150 MPa	Steel 37	5	65	< 0.15
with bursting disc	Steel 37	5	75	< 0.15

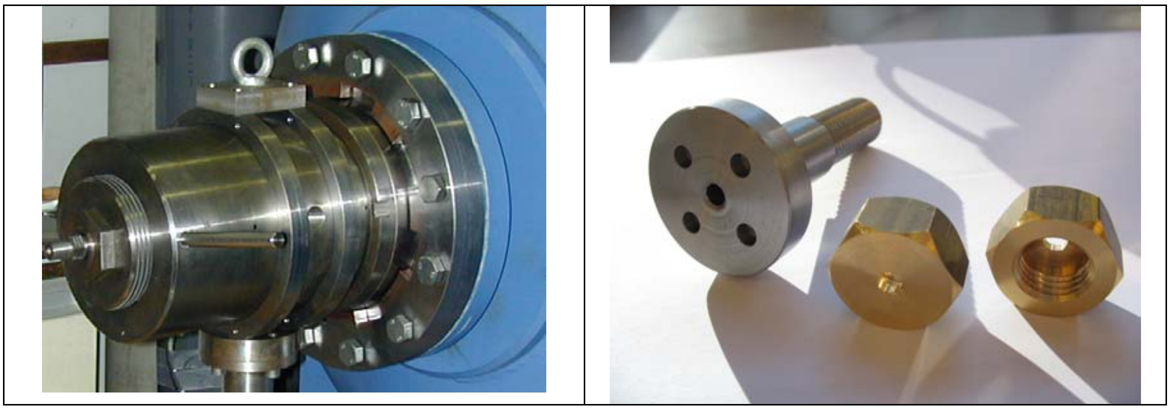

Figure 2 – The HPCV vented vessel (a) and the test items used (b) incl. bursting disc holder

Propellants

Less erosivity is one of the major goals for current propellant development, next to performance, cost, low temperature sensitivity and IM (Insensitive Munitions) or LOVA (Low Vulnerability Ammunition) properties. For this reason a number of LOVA and conventional propellants have been tested with a conventional one as a reference (RB 107). The LOVA propellants produce more hydrogen gas which is seen to be the most erosive constituent of hot gases [3,6]. General data on propellants are presented in table 3.

Table 3 Some data of the propellants tested (gases in mol%, calculated)

	Prop.	I (J/g)	T_f (K)	A_T (1) (m/s)	CO_2	H_2	N_2
NC based							
single base	RB 107	923	2508	123.8	5.86	18.34	10.28
double base (tank)	I 5790	1085	3099	45.7			
	L 5460	1128	3083	46.8	12.50	9.69	12.29
triple base	M 30	1065	3040	54.5	6.46	13.37	27.74
triple base + RDX	R 5730	1045	2817	70.9	5.54	17.06	22.16
DB + RDX + HE	K 1032	1103	2835	68.9	8.84	18.05	25.78
LOVA prop. (RDX based)							
LOVA 1	K 1016	1046	2560	123.8	0.82	31.86	20.31
LOVA 4	ETPE	1178	2993	53.7	2.53	22.60	25.31

Theory

The vented vessel test results may be presented in several ways; Lawton [3] found that the wear in erosion tests is more or less proportional to the flame temperature of the propellant to the power 4.6 on which an Erosivity number is based (A_T number).

$$A_T = (7115 / T_f)^{4.6} \quad (1)$$

$$A_G = 114 \exp\{0.0207[CO] - 3.3[CO_2] + 2.4 [H_2] - 3.6[H_2O] - 0.5[N_2]\} \quad (2)$$

$$A = w / t_o \quad (3)$$

in which t_o is a time constant, w = wear and A (3) is the wear rate in m/s.
It is remarked that eq. (2) leads to unacceptably high values for LOVA propellants and therefore this value is not mentioned in table 3.

VENTED TEST RESULTS

LPCV results

The Vented LPCV tests (loading density 0.02 g/cc) were carried out with two propellant configurations: one with the grain 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) [11] and called *cyl.* in the figure legends. The tests were performed in duplicate and the mean spread in the mass loss of the PMMA test pieces is about 7 %. The ignition of LOVA propellants is sometimes a problem: therefore some additional grains of igniter mass were added. The results are presented in figure 1 (the straight lines are only to guide the eye).

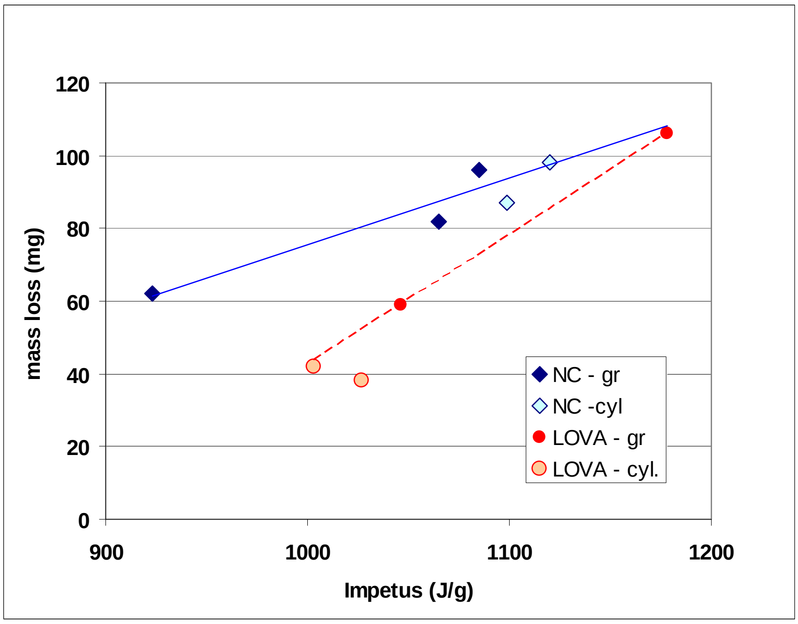

Figure 1 Erosion data obtained using PMMA test items (loading density about 0.02 g/cc)

For the LPCV results the wear is relatively high; 700 to 1150 micron PMMA per test. But also the time constant is high; 45 to 145 ms resulting in wear rates of 0.007 to 0.021 m/s of PMMA.
From figure 1 can be concluded that for small loading densities the LOVA propellants show less erosion. At Forces higher than 1150 J/g it may be the other way around.

HPCV test results

Various amounts of the reference propellant RB 107 have been tested with CrNiMo and St 37 test pieces; the results are compared and shown in figure 2. ISL had already shown that the mass loss is proportional to the loading density up to values of 0.3 (g/cc) [10].

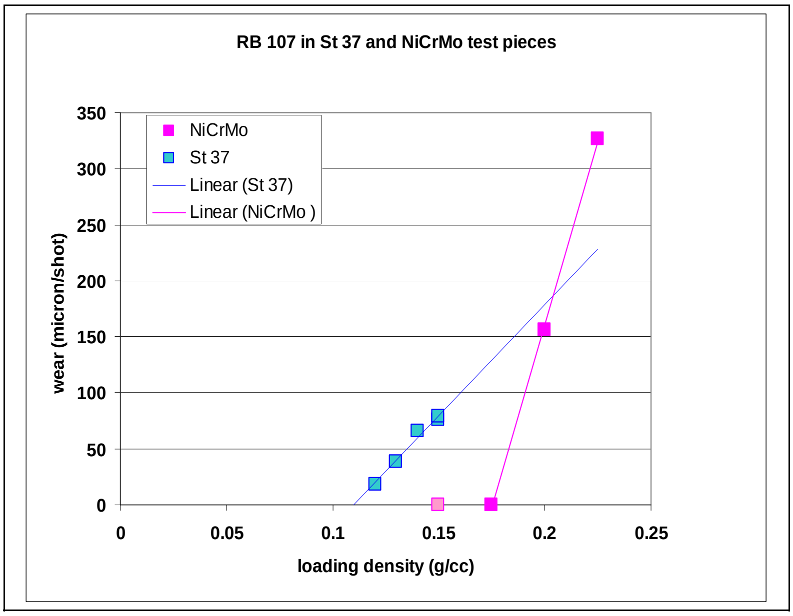

Figure 2 Results of RB 107 using St 37 and CrNiMo test pieces

From figure 2 it appears that the reactivity towards the combustion gases is quite different for both materials although the melting points are about the same.

The data of the various propellants was reprocessed as in [3] and the results are presented in table 4. The available data on a 76 mm gun is given in table 4 as well. The wear data agree reasonably well, although the time constant found in the HPCV is larger than occurring in gun firings.

Table 4 Comparison of wear data.

		Lawton [3]	TNO -HPCV	
Vented vessel test		vent hole + slit	vent hole	vh + bdisc 1)
wear	(μm/rnd)	20 - 200	10 - 160	30 – 450
time const. t_o	(ms)	5	13	15 – 60
w/ t_o	(m/s)	0.002 - 0.04	0.006 – 0.012	0.002 – 0.218
act. energ.	(kJ/mol)	37.4	-	-
prop. erosivity, A	(m/s)	0.28 – 3.8	-	-
Guns		**Data Lawton** [3]	**76 mm gun**	
wear chamber	(μm/rnd)		120 - 180	
wear tube diam.	(μm/rnd)	20 - 200		
		0.1 – 21 [1]	3.3 - 5	
w/ t_o	(m/s)	0.006 - 0.3	0.063	
act. energ.	(kJ/mol)	69.0	-	
prop. erosivity, A_G	(m/s)	30 – 210	120	

* = d / v_o 1): vh + bdisc = vent hole and bursting disc.

The wear rate (w/ t_o) is of the same order. The propellant erosivity can not be determined because of lack of bore temperature data. For the gun data the wear and the wear rate fit well in the wear range. According to [1] typical wear data are about 1 μm/round for artillery guns and about 5 - 20 μm/round for tank guns (as low as 1.9 micron/round when a TiO_2 additive was used).

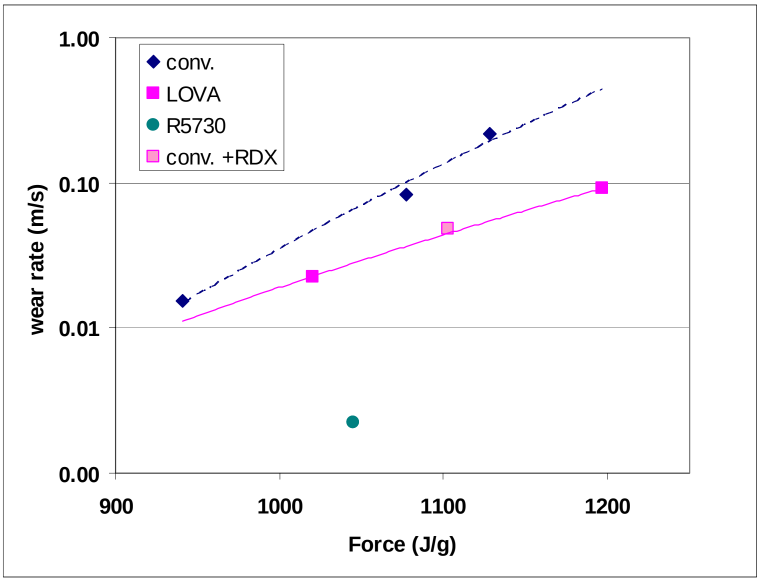

Figure 3 Wear rate as a function of the Force (HPCV data)

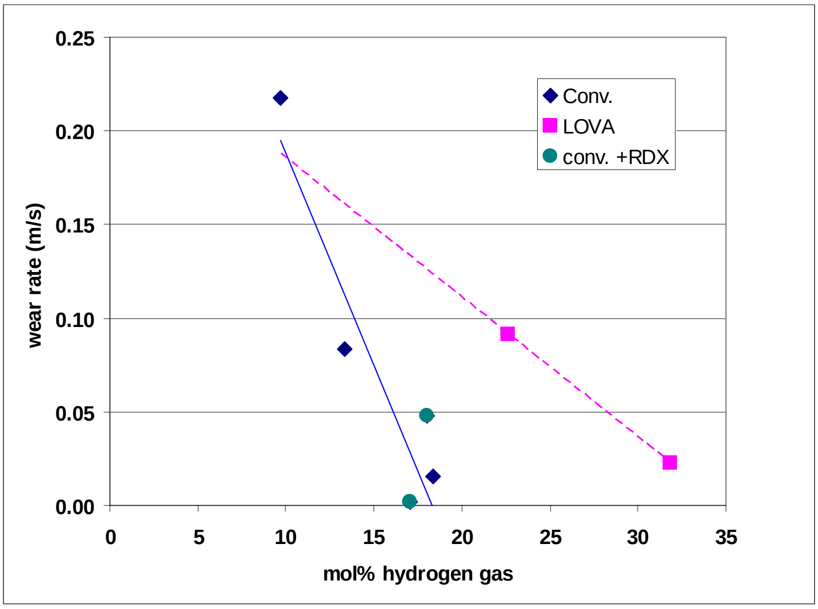

Figure 4 Wear rate vs mol% of hydrogen as measured with Steel 37 test pieces.

Caveny [7] has demonstrated that RDX containing formulations are slightly more erosive than NC based ones at comparable flame temperatures and impetus. From the TNO experiments appears that the wear rate is less for the RDX containing compositions. Especially the R5730 shows a very low wear rate compared to the other propellants.

From fig. 4 appears, that the mol% of hydrogen is very discriminating between the conventional and LOVA propellants. Kimura [6] showed for a double-choke orifice that a minimum erosion takes place at about 13 mol% of Hydrogen. The TNO data appear to confirm this minimum.

Heat input

The HPCV data on the Single base propellant RB 107 shows the existence of a critical mass, which is about 70 grams of RB 107 for the CrNiMo test material and 42 grams for the St 37 test pieces. From the mass loss and knowing some thermo physical data the heat input may be estimated. For 90 grams of the RB 107 this heat input is about 1.4 J/mm^2, while from actual firings using thermocouples a heat input of 0.9 to 1.48 J/mm^2 has been calculated.

Wear rates and heat input in the vented HPCV indicate that the results may be useful for comparing propellants under firing conditions except for the mechanical action of the projectile. The applicability of the HPCV results may be further increased by including temperature measurements.

Table 5 Heat input data.

Heat input	LPCV	HPCV	guns
in J/mm^2			
From mass loss	0.20	0 – 1.40	
Calc. [11]	0.06	4.2	
Meas. [1]			0.9 – 1.48

CONCLUSIONS

- The wear and wear rates as found in the vented HPCV are comparable to those found by Lawton [6] and in guns
- A critical propellant mass is found for the erosive behaviour. The value of this critical mass depends on heat input, propellant properties and test piece material
- Conventional propellants showed to be (slightly) more erosive than LOVA formulations on the basis of their Force
- There is a relatively strong dependency of wear rate on the mol% of hydrogen in the combustion gasses; the TNO data confirm that optimisation for conventional formulations to about 15 mol% of hydrogen may lead to small wear rate values.

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