GUN PROPELLANT DEVELOPMENT ACTIVITIES IN THE NETHERLANDS

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In the Netherlands, the experience on continuous twin screw extrusion processing of composite and conventional propellants, as well as on internal ballistics in general has been enlarged over the past years. Propellant optimisation for both performance in a gun and processibility is aided by combining models that relate both. Recent efforts include the development of LOVA propellants, new propellant charges for large calibre K.E. and E.R. munitions, and temperature independent propellant. Co-extrusion is currently being investigated in order to improve properties like ignition, performance and erosivity of conventional and LOVA propellants. Design of and optimisation of production processes for new propellant compounds are investigated.

INTRODUCTION

Starting from formulation work on composite gun propellants in the early 1990's, over the years TNO has gained extensive experience on continuous processing of these and more conventional propellants, as well as on internal ballistics in general.

Muiden Chemie International (MCI), as the only producer of – mainly – SB propellants in the Netherlands, was closed in 2004, shortly after MCI had decided to have part of its R&D activities carried out at TNO. At that time the main topic was temperature independent gun propellants as well as some novel types of (modular) charge design.

Recent efforts in the field of internal ballistics in the Netherlands include the development of new propellant charges for large calibre K.E. and E.R. munitions. The success of these developments in terms of performance and ignition properties has boosted the evolution of gun propellants and similar charges.

Currently, charge development is being performed on the whole range from small to large calibre munitions. Several test methods are available for the evaluation of performance, IM properties, erosivity and lifetime assessment.

This paper gives an overview of activities and capabilities in the field of gun propellant development in the Netherlands.

PROPELLANT MANUFACTURING

Introduction

Batch mixing and ram extrusion is the traditional manufacturing process for medium and large calibre gun propellants. Some manufacturing processes utilize continuous mixing and dewatering processes like shear roll mills and continuous extruders. Until now only few manufacturing processes utilize a continuous extruder for both mixing and shaping the propellant in one process step. The advantages of doing both processes using a continuous extruder is that the resulting propellant has a constant quality (in mixedness and shape and a high reproducibility (large batch sizes, little batch to batch variations) and the process can be adjusted easily to controllably change the properties of the propellant if needed. This level of quality, reproducibility and control is hard to achieve using (semi-) batch processes.

TNO chose to develop the extrusion process because of the advantages it gives to control propellant properties and ultimately control the performance of the complete charge, besides of reasons connected to improved safety and reduction of environmental impact and manufacturing costs. Work was started on extrusion research in the 1990s to mix and extrude LOVA formulations. Studies were performed to investigate safe processing conditions for energetic materials [1]. Currently, both composite LOVA and multi-base conventional propellants are produced by twin screw extrusion, besides other energetic materials, like flares.

Modelling

Modelling of Extrusion Processes

Rheological data (flow behaviour) of the gun propellant paste is needed to accurately model an extrusion process. A double barrel capillary rheometer was purchased to measure shear and elastic properties of materials [2]. Both shear forces, acting on the material in the flow direction, and extensional forces, acting perpendicular to the flow direction, need to be included into the rheological model to accurately model an extrusion process of gun propellants. For new formulations several ram extrusion experiments are performed and modelled to validate the rheological model.

By measuring a range of formulations and modelling the effect of formulation change on the flow behaviour of the propellant paste, it is possible to relate the formulation to the processability. If a formulation has a too high viscosity it is not safe and/or not possible to be processed.

It is possible to optimise a gun propellant formulation for both performance in a gun and processability by combining models that relate formulation to processability with models that relate formulation to performance [3]. From the ballistic simulations it is known which formulation and shape the propellant should have to perform optimally. By simulating the extrusion shaping process with a different modelling computer program, the processibility and the design of the shaping tool is evaluated.

Internal Ballistic Modelling

Thermodynamic properties are usually calculated using the ICT-Thermodynamic-Code (ICT-Code). For internal ballistic modelling TNO applies its in-house developed code TIBALCO (TNO Internal BALlistic COde). This lumped parameter code is based on STANAG 4367 [4], like IBHVG2, but is much more flexible and user friendly. Various TIBALCO modules are available for evaluation of closed vessel tests, prediction of pressures in vented vessels and simulation of guns.

Processing

Small Scale Ram Extrusion

Small gun propellant samples are produced using ram extrusion to validate the rheological and burn rate models. The ram extrusion is performed using the capillary rheometer, because of accurate temperature and throughput control and pressure drop measurement.

The material produced by the ram extrusion experiments is also used to validate the performance of the propellant and the burn rate model in a closed vessel. The material is also visually inspected on defects, websize distribution and surface quality.

Continuous Twin Screw Extrusion

Rheological modelling is also applied to optimise the continuous extrusion process. The screw design, barrel temperature profile, screw speed and throughput are optimised using an extrusion simulation package and the rheological model.

The formulation can be optimised for processability because changes in formulation are described by the rheological model. Various propellant formulations, both conventional and composite, were optimised to be manufactured without solvent and at a high throughput on a 45 mm double screw extruder using the rheological model and extrusion simulation package. From these formulations many shapes (cylindrical, hexagonal and rosette, 1, 7 and 19 perforations) and sizes (5 to 20 mm) have been extruded successfully. Using this facility TNO produces granular and stick propellant for R&D purposes on a scale up to several hundreds of kg.

Propellant Testing

Closed and Vented Vessel Testing, Burning Interruption

Developing gun propellants requires good characterization of the burning behaviour of gun propellants. TNO uses several closed vessels with volumes in the range of 43,5 cm^3 to 700 cm^3 with maximum pressures in the range of 20 MPa to 350 MPa. Both conventional and plasma ignition can be applied.

A number of these vessels can be applied as vented vessel for erosivity testing or as burning interruption test. The extent of erosion has been studied using various gun propellant types and test orifice materials [5].

Solid Propellant Electro Thermal Chemical (SPETC) Ignition

For several years now, TNO has been applying its knowledge and experience on pulse-power technology to research the Electro Thermal-Chemical ignition of LOVA gun propellants. Research was initially focused on the application of plasma channel injection in a closed vessel. A test facility was set up in order to study whether ETC ignition is suitable for initiating LOVA gun propellants. Experiments were focussed on ignitability, grain geometries and arrangement, and comparison of LOVA and multi-base conventional propellants, and the effect of energy input. Testing was performed using both an ETC closed vessel and a 70 mm ETC-test gun.

Ignitability and Flame Spreading

In order to study the ignitability of and flame spreading in a propellant charge, several full scale transparent burning chamber test set-ups have been developed. Both simulant inert propellants as well as real propellants can be tested using these facilities. By igniting a full-scale propellant charge with a suitable igniter it is possible to capture the flame spreading on high-speed video in order to investigate the initial ignition behaviour (Figure 1). These facilities are used to test new igniter systems and formulations in combination with new charge configurations.

Gun simulator and laboratory guns

To correlate lab-scale closed vessel tests and scaled or full-scale gun firings adequately, TNO is developing a gun simulator suited for both conventional as well as ETC ignition. The test-facility is currently under development and will be ready for use in 2008. For small, medium and large calibre (scaled) firings various test guns are used in TNO’s own in-door firing facilities.

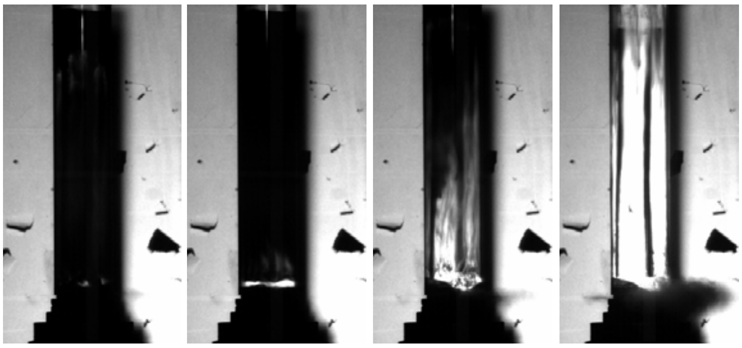


Figure 1: Flame spread experiments with multi-perf stick propellant charges in a full scale transparent burning chamber.

RECENT DEVELOPMENT PROJECTS

LOVA Propellant Development

In the 1990s TNO developed a LOVA propellant based on a HTPB curable binder to replace M1 and be used in a 155 mm artillery application. The propellant showed low burn rates and was hard to ignite.

In the following years the HTPB binder in the LOVA was changed to a non energetic TPE, to eliminate the need of a separate step for curing the propellant after processing. To be capable to process the propellant safely a little solvent (5 to 10%) was needed. The formulation was adjusted to increase the burn rate and reduce the amount of unwanted gasses (because of toxicity and barrel erosion). Later the processing solvent was replaced by a plasticizer to reduce environmental impact and production costs of the propellant.

This final formulation has been successfully extruded solventless on our 45 mm double screw extruder into 7 and 19 perforation grains of dimensions ranging from 5 to 10 mm. The propellant has a high temperature stability and low reaction from LSP tests. It was successfully ignited by plasma ignition in a closed vessel and successfully tested in a 70mm ETC gun.

Propellant Charges for Tank and Extended Range Munitions

Propellant charges based on conventional DB/TB propellant compositions have been developed for large calibre munitions, applying a multi-perforated stick propellant geometry. The continuous twin screw extrusion process, described above, is outstandingly applicable for the safe, solventless production of these stick propellants.

The well known but toxic plasticizer DBP, initially used for adjusting the burning properties, has been successfully replaced by an environmentally friendly plasticizer.

Application of stick propellant charges facilitates high charge loading densities. Charges for 105 mm APFSDS tank munition for example, consisting of cylindrical propellant sticks, have a loading density of more than 0.9 kg/dm^3. This value can be further increased by the application of multi-perf hexagonal or rosette shaped propellant sticks (close to 1.0 kg/dm^3).

The ignition system of these charges consists of a bottom igniter and an additional ignition pad. As stick propellant charges have less resistance for the gas flow along the propellant sticks, these charges are characterised by a very smooth ignition process and the absence of pressure waves. Even in the case of 127 mm munition, which is known for its risk of pressure waves [6],[7], a smooth and even pressure build-up is recorded, as shown in Figure 2.

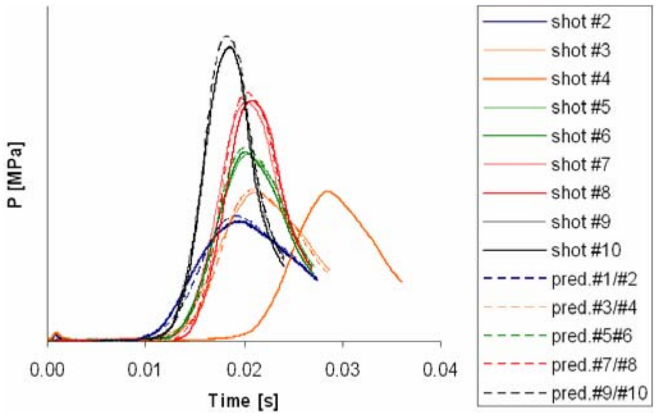
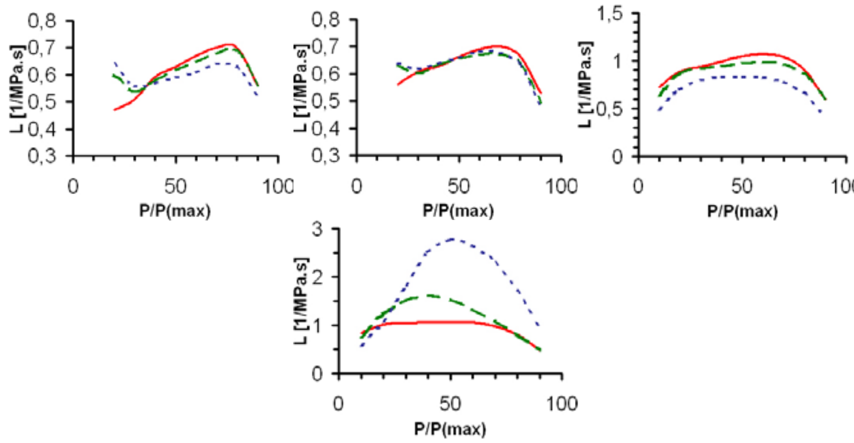


Figure 2. Pressure-time recordings for 127 mm 19-perf stick propellant charges. Pressure waves are absent as the ignition gases flow easily along the propellant sticks, and ignition times are constant, except for low charge masses.

Temperature Independent Propellant

The temperature coefficient of gun munitions is a combined result of the temperature sensitivity of several parts of the gun/munition system, of which the propellant may have a major contribution, depending on the system.

Efforts at TNO to understand the mechanisms which are responsible for the temperature dependency of gun ammunition have resulted in a reduction of the temperature coefficient for several small and large calibre gun propellant types (both ball and perforated propellants). A remarkable observation is that in some cases a reduction of the temperature coefficient in the weapon is significant while temperature independency of the propellant is not shown in closed vessel test results.



Propellant A, untreated Propellant A, treated Propellant B, untreated Propellant B, treated

Figure 3: Examples of treatment effects on the vivacity of two propellant samples.

FUTURE DEVELOPMENTS

Co-extrusion

A new processing technique investigated by TNO is co-extrusion [8]. From a performance point-of-view, energetic materials sometimes consist of more than one energetic formulation. These different formulations conventionally are pressed together, glued, dipped or impregnated. These and new products can also be manufactured by using a co-extrusion process in which two layers of different compositions are extruded simultaneously.

This process can have specific performance and/or manufacturing advantages. Examples are:

– better ignitable low vulnerable ammunition (LOVA) propellants, by co-extruding an easy ignitable composition onto the LOVA grain
– propellants with increased progressivity by co-extruding propellants with different burning rates
– diminished barrel erosion by extruding a propellant formulation with a low flame temperature and/or erosion reducing additives on the outside of the propellant grain.

Co-extrusion is a well-known technique for non-energetic polymer processing, like film blowing, pipe and profile extrusion. However, for energetic materials with complex flow behaviour, due to high solid loading and processing close to the flow point, the same control parameters might not be valid or be significantly different. At TNO small scale co-extrusion experiments have been performed to investigate the effects of these control parameters on product quality.

On small scale propellant strands have been successfully co-extruded with an outer layer with a different burning law than the core of the propellant. Work is in progress to be capable to co-extrude multi-perforated strands and complex shapes and to scale up the process to two continuous extruders.

New Energetic Formulations

In order to meet the requirements for future weapon concepts more energetic gun propellants are needed with higher densities. At the same time these new propellant formulations should be environmentally benign (‘green’ munitions) and should have ‘IM’ properties. Most importantly, the new formulations should enhance the performance while reducing, among other things, gun barrel erosion and flame temperatures. These requirements can be achieved in various ways, each way having its advantages and disadvantages. In order to increase the energy density of the propellant formulation CL-20 or TNAZ can be used, whereas for lowering the flame temperature and reducing gun barrel erosion for instance FOX-7 and BTATz can be used. The high nitrogen compounds, like BTATz, will produce nitrogen gas upon decomposition, herewith reducing the erosivity. For this purpose also more generic high nitrogen compounds can be used.

One of the major stumbling blocks for using most of the above-mentioned materials in widespread applications is their price. The research at TNO Defence and Security is focused on, on the one hand, process optimization and process intensification of these compounds to make them on a large scale available in an economically viable manner and, on the other hand, designing new formulations containing these materials.

REFERENCES

[1] H.W.R. Sabel, E. Schonewille, ‘Extrusion trials with a TSK045 twin screw extruder’, Proc. 29th Int. Ann. ICT Conference (1998)

[2] A.C. Hordijk, H.W.R. Sabel, and J.M. Mul, ‘Capillary extrusion rheometry and extrusion of propellants and propellant simulants’, Proc. 31st Int. Ann. ICT Conference (2000)

[3] Caspar Schoolderman, Aat Hordijk, ‘Extrusion processing and modelling at TNO’, Proc. 36th Int. Ann. ICT Conference & 32nd Int. Pyrotechnics Seminar (2001)

[4] ‘Thermodynamic interior ballistic model with global parameters’, STANAG 4367, Ed.2

[5] Aat C. Hordijk, Chris A. van Driel and Michiel J.G. Bakker, ‘Propellants and Propellant Erosivity’, Proc. 23rd Int. Symp. on Ballistics (2007)

[6] C.W. Nelson, F.W. Robbins, P.S. Gough, 'Predicted Effects of Transient Burning on Gun Flamespreading', Army Ballistic Research Lab Aberdeen Proving Ground MD, ADA054639 (1978)
[7] Chang, Lang-Mann, 'Formation of High Amplitude Pressure Waves in a 5-In./54 LOVA Charge', Army Ballistic Research Lab Aberdeen Proving Ground MD, ADA187177 (1987)
[8] C. Schoolderman, M. Zebregs, C.A. van Driel, A.C. Hordijk, 'Co-Extrusion of Gun Propellants', Proc. 37th Int. Ann. ICT Conference (2006)