19th International Symposium of Ballistics, 7–11 May 2001, Interlaken, Switzerland

# BALLISTIC SHELF LIFE OF PROPELLANTS FOR MEDIUM AND SMALL CALIBRE AMMUNITION – INFLUENCE OF DETERRENT DIFFUSION AND NITROCELLULOSE DEGRADATION

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The reasons for ageing-induced changes in interior ballistic behaviour of small and medium calibre ammunition have been investigated.
In case of the 5.56 NATO ammunition, two different propellants have been subjected to accelerated ageing at 71°C for 4 weeks. The ammunition filled with ball powder showed an ageing-induced increase in peak pressure of 75 MPa, whereas ageing of the ammunition with the alternative EI propellant (EI = extruded impregnated) did not result in a peak pressure rise. Diffusion could be identified to be a dominating factor.
Further results are presented, proving that the ageing-induced changes in interior ballistic behaviour of surface coated medium calibre propellants directly correlate with the extent of deterrent diffusion. In certain propellants, deterrent diffusion is so fast that it can be monitored even at room temperature. On the other hand, excellent ballistic shelf life can be obtained if surface coatings with low diffusion potential are applied.

## INTRODUCTION

Due to the increasing number of "out-of-area" missions, *service life of ammunition* becomes a very important issue also for the nations in the moderate climatic regions. The service life of ammunition is often limited by propellant ageing.

As can been seen from Figure 1, *service life of propellants* consists of two components – *safe life* and *functional life.*

The *safe life,* also called *chemical shelf life,* covers the period of time during which the propellant can *safely be stored* without representing a hazard to its environment. The safe life is limited by the extent of chemical ageing reactions, such as decomposition of nitric esters and reactions of these decomposition products with stabiliser.

The *functional life* or *ballistic shelf life* is the period of time during which the propellant / ammunition can safely be used or during which the interior ballistic requirements remain fulfilled. The main propulsion-related factors which limit the functional life are *molecular mass reduction of the nitrocellulose* as well as *diffusion* and *incompatibility processes.*

Therefore, *service life* is the interval during which the propellant can be s*tored, handled and used without any danger.*

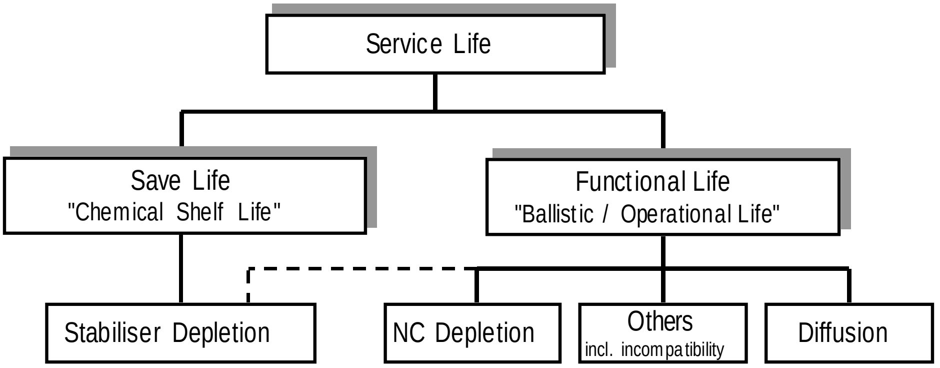


Figure 1: Service life of propellants, including limiting factors.

## PROPELLANTS FOR SMALL AND MEDIUM CALIBRE AMMUNITION

In small and medium calibre ammunition, three different propellant types are used almost exclusively: *single base propellants*, *"semi double base" propellants* (e.g. ball powders and EI propellants; with nitro-glycerine contents between 2% and 15%), and *double base propellants* (usually containing more than 15% of nitroglycerine or other blasting oils). In order to obtain the required burning characteristics and to meet the performance requirements, *surface coating of these propellants is essential.*

## FUNCTIONAL LIFE OF SINGLE BASE PROPELLANTS

The ageing of *coated single base propellants* very rarely results in problems: The rates of chemical ageing (regarding stabiliser depletion and nitrocellulose degradation) are very low. Furthermore, the deterrents commonly used for surface coating diffuse very slowly into the single base propellant grains. As a consequence, only minor changes in interior ballistic behaviour occur even under extreme ageing conditions, and both *excellent functional life and service life* values can be predicted (see Figure 2).

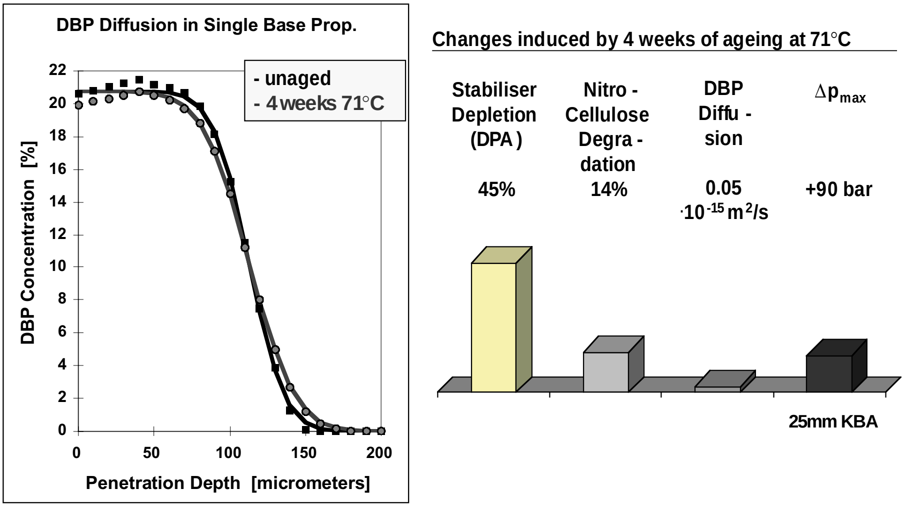


Figure 2: Changes in single base propellant, coated with dibuthyl phthalate (DBP), after 4 weeks of ageing at 71°C. Even after this “extreme temperature storage”, the surface coating concentration profiles remain essentially unchanged. As also the extent of nitrocellulose degradation is small, only minor changes in ballistic behaviour occur (in this example, a peak pressure rise of 9 MPa appears if fired in the 25 mm KBA system compared to non aged ammunition). The diffusion rate was determined as described in [2].

## FUNCTIONAL LIFE OF DOUBLE BASE PROPELLANTS

On the other hand, it was found that most deterrents diffuse quickly into *double base propellants*. In one particular case (which is known for its reduced functional life), the deterrent diffusion is so fast that it can be monitored not only at elevated temperatures but even at room temperature (see Figure 3). Furthermore, also the rate of chemical ageing is inherently increased in double base propellants (due to the lower stability of nitroglycerine compared to nitrocellulose). As a consequence, it is *very difficult to obtain sufficient functional life and service life* values with *coated double base propellants* for small and medium calibre applications.

## FUNCTIONAL LIFE OF “SEMI DOUBLE BASE” PROPELLANTS

With only relatively small contents of nitroglycerine (or other blasting oils), the so called “semi double base” propellants lie in between single and double base propellants.

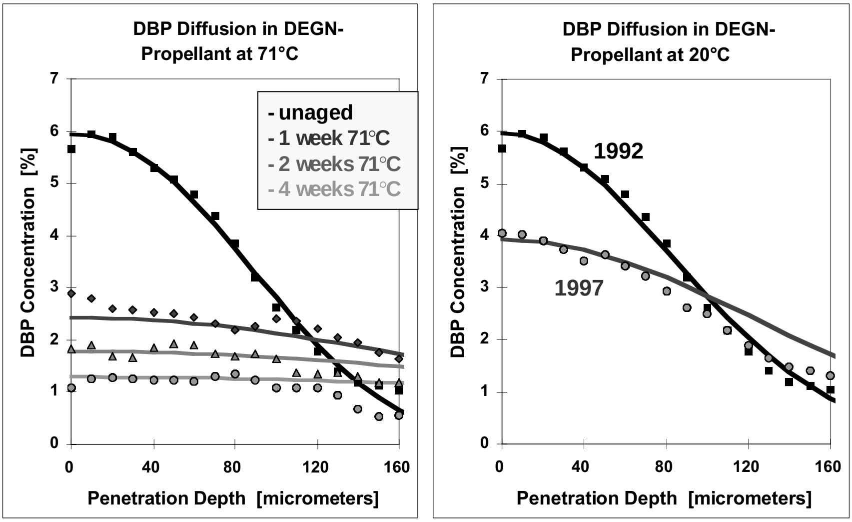


Figure 3: Changes in deterrent concentration profile in a double base propellant for 25 mm APDS ammunition, after 1, 2, 3, and 4 weeks of accelerated ageing at 71°C, as well as after 5 years of natural ageing. The extreme extent of deterrent diffusion (1000 times faster as compared to Figure 2) resulted in unacceptable interior ballistic changes after only a few years of ammunition storage.

In these *"semi double base" propellants*, both chemical ageing and deterrent diffusion are somewhat higher than in single base propellants. Especially if deterrents of small molecular weight (such as DBP, DNT, Camphor, Centralite) are applied, deterrent diffusion might be too high to ensure sufficient functional life.

On the other hand, if carefully manufactured base grains are coated with optimal types and amounts of blasting oils and oligomeric / polymeric deterrents, excellent ballistic performance can be combined with sufficient functional life and service life. This is demonstrated in two examples.

## Functional Life of Propellants for 5.56 mm Ammunition

In case of the propellant for 5.56 mm NATO ammunition, the behaviour of the well established *ball powder* as well as of an alternative variant, the so called *EI propellant* (EI = extruded impregnated) has been investigated.

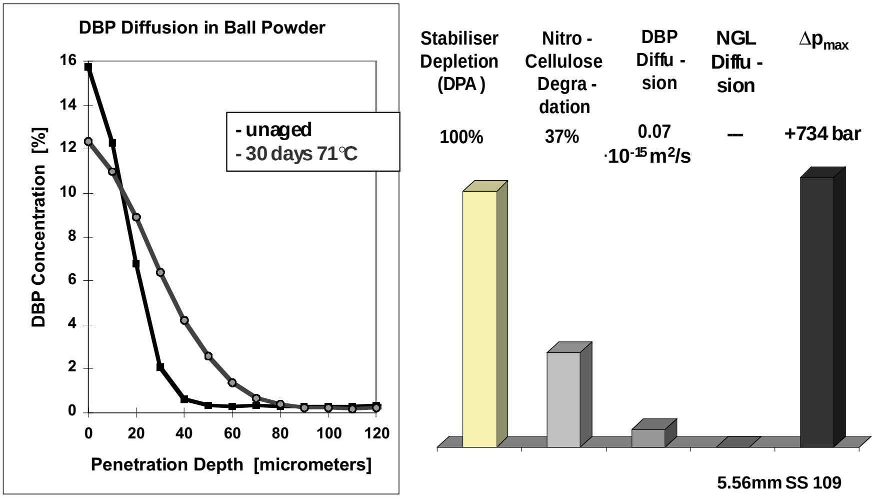


Figure 4: Changes in deterrent concentration profile and other characteristics of a ball powder for 5.56 mm ammunition after 4 weeks of ageing at 71°C.

After accelerated ageing for 4 weeks at 71°C, ammunition filled with *ball powder* showed an increase in peak pressure of 73 MPa (see Figure 4). This increase has to be regarded as critical – in particular at high temperatures ("out-of-area" missions), a reduced functional life has to be expected.

The reasons for this increase in peak pressure have been investigated. Due to the potassium nitrate, chemical ageing is increased in this ball powder (as can be seen by the fact that the stabiliser diphenylamine is fully consumed after 4 weeks at 71°C). On the other hand, the amount of nitrocellulose degradation is not unusually high and should not markedly contribute to the ballistic changes. The measured peak pressure increase of 73 MPa seems to be caused by the DBP diffusion. In fact, interior ballistic calculations (IBHVG 2) show that the peak pressure is mainly determined by the DBP concentration within the outer 20–40 µm of the grains, and that the determined amount of DBP diffusion might well result in an increase in peak pressure of 60–100 MPa.

When the rounds are filled with *EI propellant*, even a small decrease in peak pressure is detected after 4 weeks of ageing at 71°C (see Figure 5). In this propellant, chemical ageing as well as diffusion rates for nitroglycerine and oligomeric deterrent are considerably low (if the larger grain dimensions compared to ball powder are taken into account). With the use of EI propellant in the 5.56 mm ammunition, no dangerous increase in peak pressure appears even after extreme temperature storage – both *functional life and service life values exceed 20 years.*

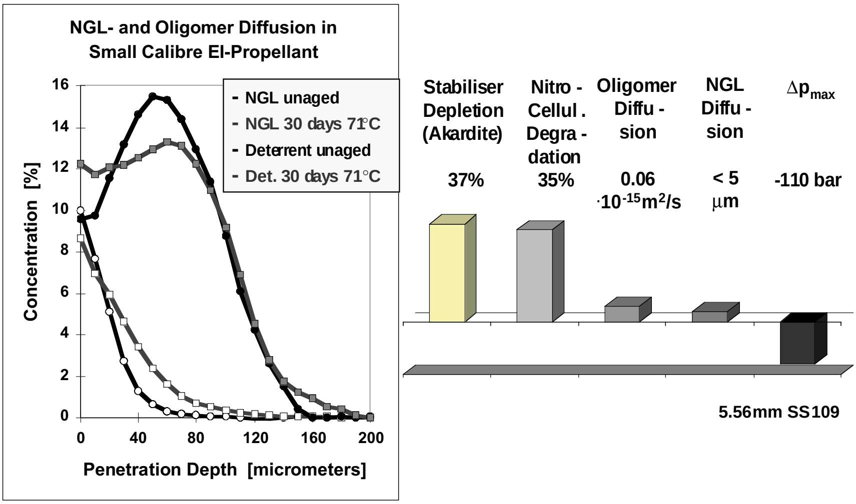


Figure 5: Changes in oligomeric deterrent concentration profile and other characteristics of a extruded impregnated (EI) propellant for 5.56 mm ammunition after 4 weeks of ageing at 71°C.

## Functional Life of Propellants for Medium Calibre Ammunition (20–50 mm)

During the last years, the *EI-technology* was successfully qualified and introduced in different *high performance medium calibre applications* (25 mm APFSDS, 27 mm APFSDS, 30 mm APFSDS and Multi Purpose, 35 mm APFSDS; see [3]). The ageing of *EI propellants* was thereby thoroughly investigated. In all qualification procedures, excellent safe life and functional life values were established.

The ageing processes taking place in such EI propellants are demonstrated for the 27 mm APFSDS round (see Figure 6). Thanks to the carefully optimised surface coating, both nitroglycerine and deterrent diffusion are at such a low level that no increase in peak pressure appears even after 4 weeks of ageing at 71°C.

Obtaining such good diffusion and ballistic stability is, however, not self-evident. In the early stage of development, other types of blasting oils and deterrents in other concentration ranges have been used. In the worst case, propellants were obtained with, compared to today's EI propellants, 10 times higher blasting oil and deterrent diffusion rates, leading to unacceptably high peak pressure rises of up to 180 MPa after extreme temperature storage (see Figure 7). For such propellants functional life is reduced to about 10 years: As a consequence, this branch of development was stopped.

Figure 8 clearly shows that the changes in peak pressure, induced by ageing, in fact correlate to the deterrent diffusion rates. Despite the fact that the 11 propellants were tested in 10 different ammunition systems, a clear correlation is visible.

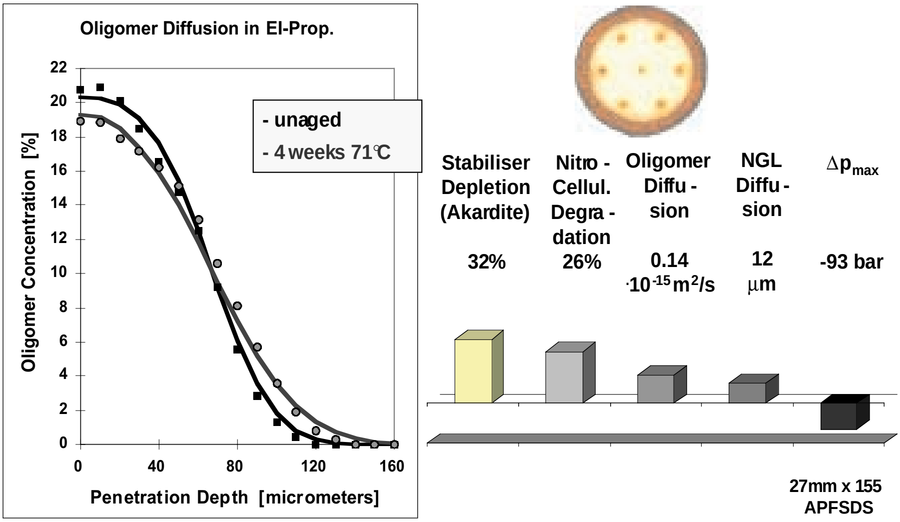


Figure 6: Changes in deterrent concentration profile and other characteristics of an extruded impregnated (EI) propellant for 27 mm APFSDS ammunition after 4 weeks of ageing at 71°C.

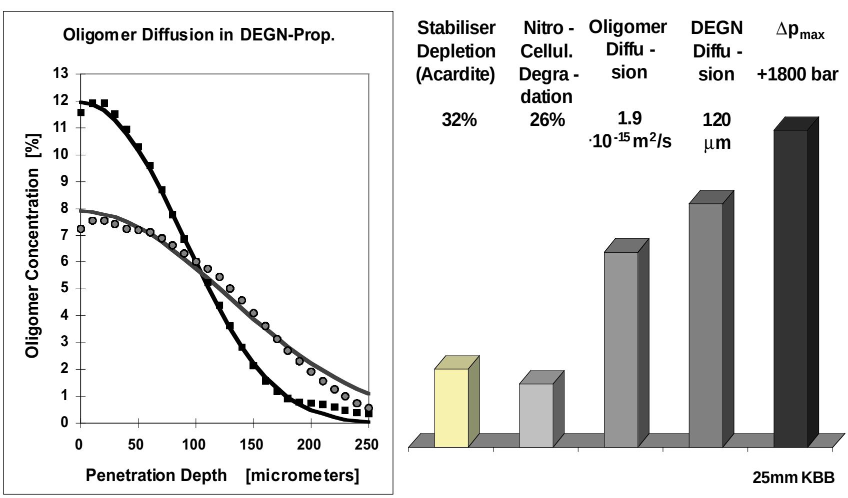


Figure 7: Changes in deterrent concentration profile and other characteristics of a semi double base propellant based on diethyleneglycoldinitrate (DEGN) for 25 mm KBB ammunition after 4 weeks of ageing at 71°C.

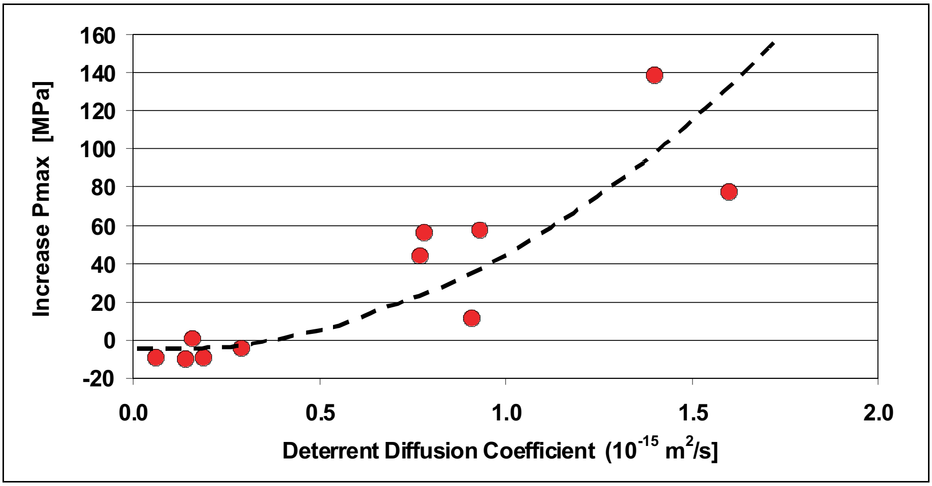


Figure 8: Correlation of increase in peak pressure, induced by 4 weeks of ageing at 71°C, against deterrent diffusion rate. Non aged and aged samples of 12 different propellants were fired in the designated ammunition systems (25, 27 and 30 mm APDS and APFSDS).

## CONCLUSIONS AND OUTLOOK

Ageing of propellants, in particular the diffusion of surface coatings, has been demonstrated to strikingly influence the functional life of ammunition.

Knowledge of these processes is therefore essential in order to optimally design the next generation of highest performance propellants for small and medium calibre ammunition.

It has been proven that, if this knowledge is applied, coated "semi double base" propellants with excellent ballistic performance, combined with sufficient functional life and service life, can be successfully developed and produced.

Research is under way in order to further improve performance and resistance towards ageing of such propellants. These activities include the substitution of nitroglycerine by less sensitive energetic plasticizers as well as the search for polymeric deter-rents with even lower diffusion potential, including cross-linked polymers.

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