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

INVESTIGATIONS FOR MODELING CONSOLIDATED PROPELLANTS

C. Bonnet, P. Della Pieta, C. Reynaud

SNPE, Centre de Recherches du Bouchet, BP N° 2, 91710 Vert le Petit, France

The main characteristics of ammunitions with consolidated charge are an important part of the propelling charge located around the projectile and the presence of ullage or granular propellants between the projectile and the charge. Experimental observations have showed that ignition phase of a consolidated charge is significantly different from the one of a granular charge. So, understanding, control and optimisation present a formidable challenge. In order to better understand the consolidated propellants ballistic behaviour, experimental set-up and comprehensive theoretical model are under development. The paper reports both points.

INTRODUCTION

The concept of block of consolidated gun propellant is studied at SNPE for several years (at the end of the 70s). These blocks were proposed in developments of loads going from 5,56 to 45 mm and studied in diameter 90 mm to be proposed in large calibre ammunition. According to the function provided by the block of consolidated gun propellant (mass increasing, progressivity increasing, facilitated by load, assistant to the passage of a tail of projectile…), their dimensioning requires the knowledge of their ballistic and mechanical behaviours as well from a point of view theoretical as experimental. These studies made to SNPE have for objective to establish a model of behaviour integrated into the code of numeric simulation of internal ballistics of gun MOBIDIC-NG.

EXPERIMENTAL INVESTIGATIONS

The development of the consolidated propellants needs both knowledge of the gun propellant composition (like the choice of the binder) and the quality of the block such as binder composition, apparent density or geometry. These various parameters are preponderant factors for the consolidated propellants ballistic behaviour. To understand it, mechanical and combustion studies were realised on single and multi-base propellants from 5,56 to 90 mm calibre guns.

Propellants deconsolidation observation

The packing does not break the grains but deforms and closes the perforations. Thus, the debit is different and the late opening of the perforations increases the progressivity of the overall charge.

Mechanical test

The mechanical test consists to apply a radial compression on the consolidated propellant and to record the breaking strength (Figure No. 1).

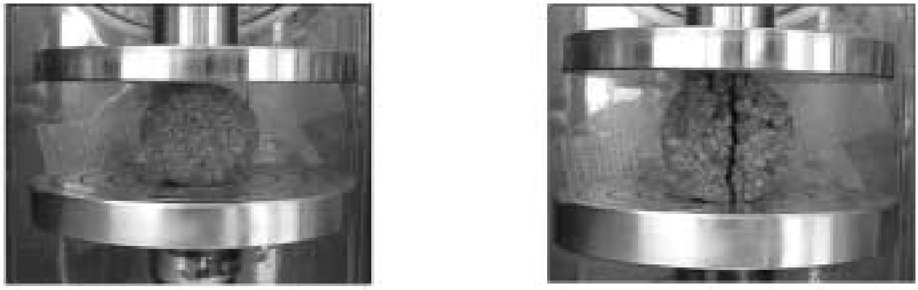


Figure 1.

Extinction test

A simulator equipped with a shear disc (Figure No. 2) constitutes the experimental set up. The test consists to blow out the consolidated propellant combustion. Single base propellants (D = 30 mm, H = 30 mm) with 1,35 and 1,45 g/cm^3 apparent densities were tested.

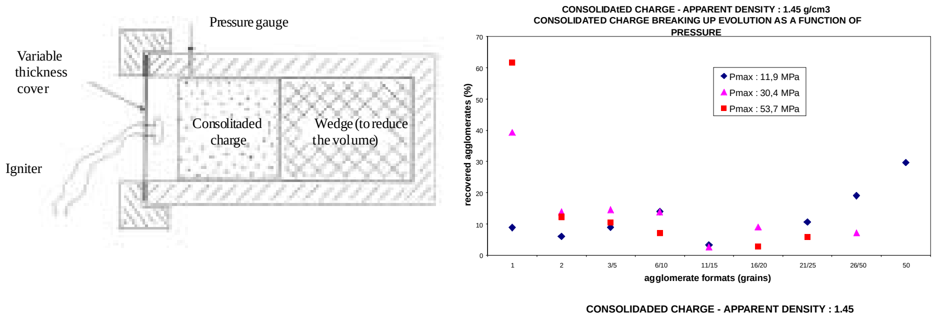


Figure 2.

The apparent density being the same, higher is the rupture pressure, smaller are the agglomerates. Grains are found from 60 MPa with the smaller apparent density. With the higher apparent density, there are approximately 8% of agglomerates formed by 21 to 25 grains at 53 MPa.

Home
Table of Contents

Closed vessel characterisation with fixed consolidated propellant

The closed vessel has been modified to hold the consolidated charge into a cylinder. Figure No. 3 shows the experimental set up. Tests were performed on single base propellant (D = 40 mm, H = 30 mm) with 1,35 and 1,45 g/cm^3 apparent densities. Internal and external pressures were recorded and values of the difference are about 9 MPa with 1,35 g/cm^3 apparent density and 13 MPa with 1,45 g/cm^3. This difference of pressure increases with the apparent density of the consolidated propellant and corresponds to the break-up or its beginning. From this study, we can qualitatively conclude that consolidated charges are impermeable.

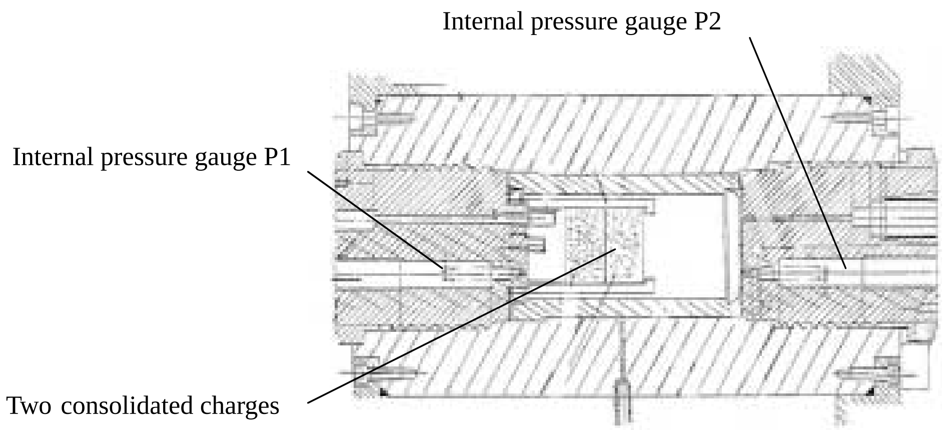


Figure 3.

Classical closed vessel test and mechanical/combustion relation

Tests are performed in closed vessel with standard igniter. Single, double and multi-base consolidated charges are studied with different densities, diameters and binders. We determine the percentage of the combustion surface area reported to the consolidated grains surface area (defined as a geometry coefficient G). Some results of these tests are given in the following figures for which double base propellant with two consolidated propellant diameters 90 mm and 50 mm were used. On the Figures No. 4 and No. 5, the geometry coefficient G is represented as a function of the maximal radial breaking strength alone or reported to the consolidated propellant section.

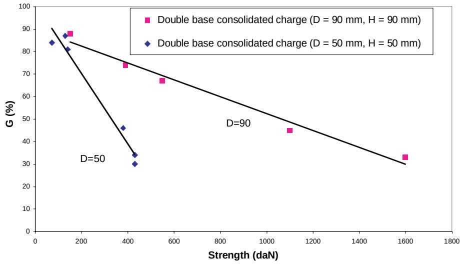


Figure 4.

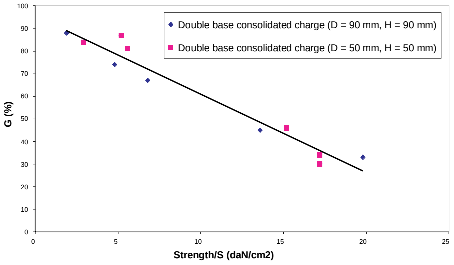


Figure 5.

At same G, bigger is the block, higher is the force. The figure 5 shows an interesting result since values of the geometry coefficient G are on the same curve. Next Figure No. 6 shows the influence of the couple binder/propellant on the coefficient G.

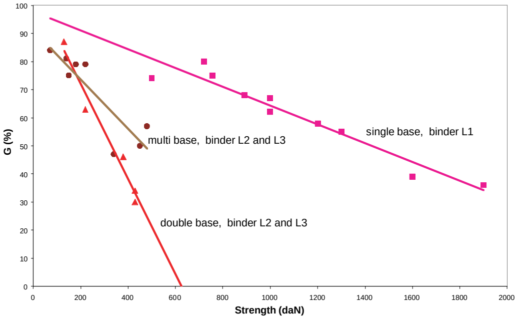


Figure 6.

THEORETICAL MODEL

In this section, model of two-phase flow and an emerging model of consolidated charge introduced in MOBIDIC-NG code are presented. More recently, emphasis has been placed on fully two-dimensional interior ballistics code MOBIDIC-NG. This code is used in French military industries since it has been delivered to ETBS and GIAT Industries. Efficient numerical discretisation is utilised to solve two-phase flow everywhere treating in this way large-scale void between regions occupied by the propellant or after-body projectile [1]. Code modularity and case of code modification are being incorporated. Applications to solid propellant systems as well as numerical solution method are also presented in reference [2].

Model of two-phase flow

The model of two-phase flow (used for a granulated charge) is based on the theory of multiphase mixtures which is formulated to treat each phase as fully compressible and in total thermodynamic nonequilibrium. This model consists of partial differential equations

Home
Table of Contents

of conservation applied to each phase and interactions between the phases enter the theory via source terms that are added to the single phase conservation laws. More constitutive relations or equations are introduced to better describe the system but they do not change the meaning of the basic model stated as:

Conservation of mass : $(\rho_a)_t + \vec{\nabla}.(\rho_a \vec{V}_a) = c_a^+$

Conservation of momentum : $(\rho_a \vec{V}_a)_t + \vec{\nabla}.(\rho_a \vec{V}_a \otimes \vec{V}_a + \phi_a p_a I) = \vec{m}_a^+$

Conservation of energy : $(\rho_a E_a)_t + \vec{\nabla}.[(\rho_a E_a + \phi_a p_a)\vec{V}_a] = e_a^+$

To close the set of equations, changes in the solid volume fraction other than due to combustion are related to the pressure differences existing between the two phases and the contact forces between grains:

$$(\phi_s)_t + \vec{V}_s . \vec{\nabla}\phi_s = \frac{c_s^+}{\gamma_s} + \frac{\phi_s \phi_g}{\mu}(p_s - p_g - \beta_s)$$

The state of the mechanical desequilibrium is driven by the viscosity of compaction that expresses the velocity at which pressure equilibrium is reached. In our situation, it is reasonable to assume pressure equilibrium. To do that, we force the gas and the solid pressure to be in pressure equilibrium by using a relaxation technique.

Modelling consolidated charge

In conventional guns, progressivity of the propelling charge is usually enhanced through surface area modification (multiperforated grain geometries) or chemical tailoring of the propellant linear burning rate. In a consolidated charge, enhanced progressivity results from a surface area increase as the compacted charge burns through or fractures into smaller aggregates along stress lines in the charge. This break-up may be aided by external or internal pressurisation.

To model this phenomenon, we adopt a continuous deconsolidation process of the compacted charge toward a granular charge. A numerical problem that is linked to the modelling problem is that of distinguishing without ambiguity between the two materials that may be involved (granulated or consolidated charge) since the behaviour of these materials is different.

The deconsolidation process is modelled by a reaction progress variable I which denotes the deconsolidation fraction of the compacted charge and accordingly assumes values between 1 (granulated propellants) and 0 (consolidated charge). Being carried with the fluid, *I* has an initially known distribution and its evolution is governed by an advection equation $\dot{I} = 0$ if no deconsolidation process occurs or by a rate equation $\dot{I} = r$. The reaction rate *r* allows a controlled release of surface area through a continuous deconsolidation process. To model this reaction rate, a combined experimental and theoretical approach is necessary. For computational convenience, we have used to express this equation in a conservation form.

Home
Table of Contents

According to the value of I, it should be possible to identify each material during the course of calculation and so choose the corresponding modelling. Although the development rate of the propelling charge surface area is the main factor of interest, other factors are also important and necessary for a more complete two-dimensional modelling of the process. Details such as gas permeability or state of compaction are quite difficult to evaluate for consolidated charges. In view of experimental data on this subject [3], we can qualitatively say that gas permeation does not occur (indicating large interphase drag). It implies that fluid velocities are in equilibrium and the relaxed solution for the velocities is then the center of mass velocity. This condition no longer applies in the packed bed where the finite value of the drag force furnishes an information on the velocity difference between phases. To model dynamic compaction, we make the simplest assumption that the consolidated charge is not allowed to lose its shape (no compaction occurs).

Numerical simulations

As a test problem, MOBIDIC-NG is used to study the displacement of a packed or consolidated charge under pressure effects delivered by an igniter. The configuration, with ullage located on both sides of the charge and described with a solid volume fraction equal to 10^{-7} is given by the figure 7. For the simplicity of analysis, simulations are performed with an inert propelling charge and one-dimensional geometry.

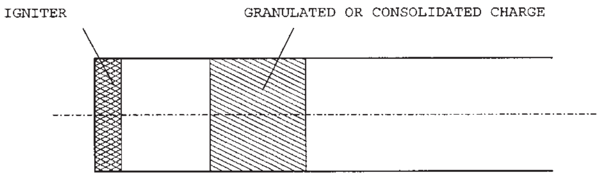
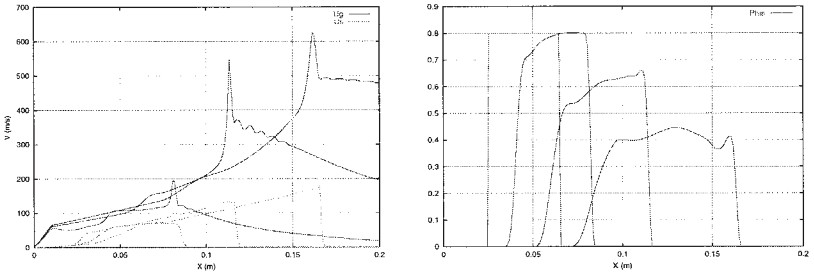


Figure 7.

Initial solid volume fraction is 0.8. With a packed bed, the grains are dispersed by igniter output gases. The propelling charge is permeable to the gas phase and the mechanism of drag serves to move the propellant and to modify the solid volume fraction. Time-evolution of the mixture is shown in figure 8 where velocities and solid volume fraction are displayed.

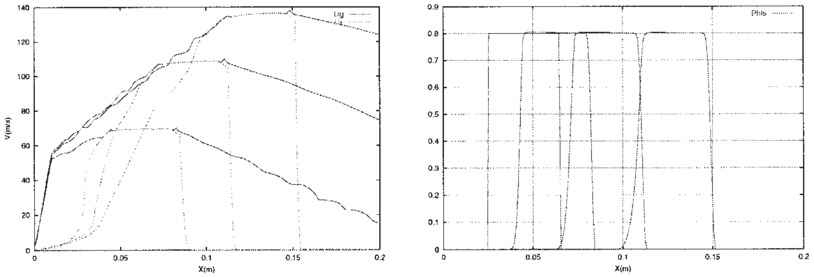


VELOCITIES

SOLID VOLUME FRACTION

Figure 8.

Results for a consolidated charge are given by the Figure 9. This charge acts like an accelerating projectile and the solid volume fraction does not change.



VELOCITIES

SOLID VOLUME FRACTION

Figure 9.

In particular, the figure illustrates the velocities of the two phases that are equal inside the consolidated charge. The deconsolidation factor curve is similar to the solid volume fraction one and is able to identify and to follow propagating material interfaces. This interface is propagated through the solution space with low diffusive character.

CONCLUSIONS

The experimental characterisations in mechanics and combustion of the consolidated gun propellant made it possible to better know their behaviours according to the significant parameters that are the composition of the powder, the quality and the quantity of binder, the apparent density and the geometry of the block.

An emerging model introduced in MOBIDIC-NG for studying consolidated charge is developed and studies carried about it have shown that a combined experimental and theoretical approach leads to develop or to combine appropriately detailed submodels so that their interactions within the overall interior ballistics model provide an increased predictive or diagnostic capability.

REFERENCES

1. P. Della Pieta, “Numerical Simulation Of Two-Phase Flow With Strong Porosity Gradients”, *Workshop On Unsteady Combustion And Interior Ballistics, St. Petersburg, June 26–30, 2000.*
2. P. Della Pieta, C. Reynaud, “Numerical Investigations For Modeling Interior Ballistics Two-Phase Flow”, *European Forum On Ballistics Of Projectiles, Saint-Louis, April 11–14, 2000.*
3. R. Briand, P. Della Pieta, C. Reynaud, M.F. Dubois, P. Racimor, D. Roller “Modélisation des munitions de 45 mm du moyen calibre futur balistique 1 temps”, *Internal Report, September 1997.*

Home

Table of Contents