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

BURNING CHARACTERISTICS OF FOAMED POLYMER BONDED PROPELLANTS

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Foamed polymer bonded propellants show performance on high energy level combined with variable material and burning characteristics. Properties can be varied in a wide range by changing the formulation as well as by adjusting the internal porous structure. Closed vessel test results are presented showing the dependence of the burning behaviour on the porous structure. Since current predictions of interior ballistics simulations fail when based on a straightforward use of Vieille's law a new model has been developed. Simulation results describing the special interior ballistic behaviour of porous charges on that basis are presented. Explicit consideration of the internal structure in the model enables the qualitative description of the burning characteristics found in experiments and are a basis to predict the influence of parameter changes on them.

INTRODUCTION

Foamed polymer bonded propellants developed by Fraunhofer ICT show variable material and burning characteristics [1,2]. In addition the charges have performance on a high energy level. Realised applications are combustible cases and caseless ammunition [3,2].

Foamed propellants can be produced with a high reproducibility by reaction injection moulding. The properties of these foamed propellants can be varied in a wide range by changing the formulation as well as by adjusting the internal porous structure. Therefore a special interior ballistic behaviour can be achieved without changing the shape of the propellant. Since foamed propellants can be easily produced even in very complex shapes, further applications like modular charges, fixing of ammunition components by surrounded foam and gradient charges are possible.

The burning characteristics of these porous charges show specialities compared to standard gun propellants. The mass conversion rates lie essentially above those obtained by the linear burning of compact materials. The burning behaviour deviates from Vieille's law and current predictions of interior ballistic simulations fail when based on a straightforward use of it [4,5]. To simulate the closed vessel behaviour found in experiments a phenomenological model has been developed [6] and improved [7].

In this proceedings a brief outline concerning the measured and modelled special burning characteristics is given.

EXPERIMENTS: INFLUENCE OF THE POROUS STRUCTURE ON BURNING CHARACTERISTICS

Burning characteristics and mechanical properties of foamed propellants are determined by components and additives, but also by porosity and inner surface (i.e. in other words density and pore size distribution). The porous structure can be varied in a wide range by additives like catalysts, foaming agents, foaming initiators and stabilisers and by processing parameters like temperature. Based on this foamed propellants with different pore size distribution but constant density (charge mass/charge volume) can be achieved. Fig. 1 presents the effective linear burning rate of two porous charges of same density (0,765 g/cm^3) in comparison with gun propellant JA2 (density 1,586 g/cm^3).

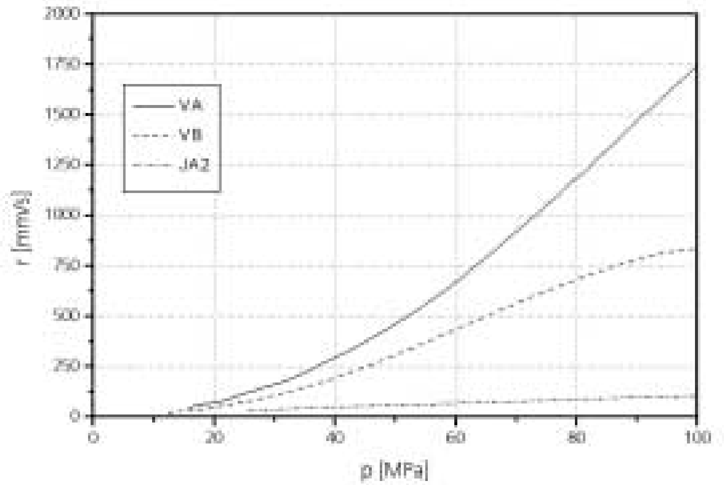

Figure 1: Effective linear burning rate (JA2 and porous charges VA and VB).

Caused by the pores the mass conversion rates are essentially increased compared to standard gun propellants. This leads to the characteristic massively enlarged effective linear burning rates. In Fig. 2 a photograph of a foamed porous charge is shown on the left side. Also the influence of pore diameter and total pore volume on the inner surface is presented for the simplification that all pores are of identical diameter.

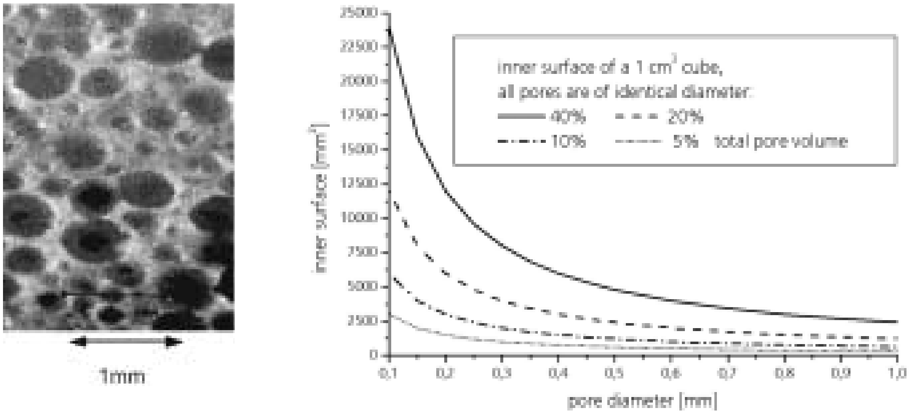

Figure 2: Foamed charge, influence of pore diameter on inner surface.

Fig. 3 presents the influence of density changes and the strong influence of microporosities on the dynamic vivacity measured in closed vessel experiments. The samples had cube geometry (1 cm^3) and the non-porous charge (with density 1.56 g/cm^3) shows the degressive burning behaviour normally found for compact charges with cube geometry.

Using the form function of a non-porous propellant and Vieille's law to analyse closed vessel data, linear burning rates are achieved which are not independent from the loading density. The gradient is not identical as it used to be for non-porous gun propellants. Fig. 4 presents the effective linear burning rate derived from experiments with cubic samples (1 cm^3) in a 106 ml closed vessel. Influences of variations of additional basic parameters are presented in [1,2,4,7]. Since the density of the charge and the ratio of energetic fillers can influence the burning characteristics in an opposite manner, burning rate and specific energy can be adjusted independently from each other. For example, keeping the pore size distribution constant while increasing the density of foamed propellants causes a higher energy density but decreases the burning rate at the same time.

Concerning standard propellants Vieille's law describes the dependence of the burning rate on pressure with sufficient accuracy over three magnitudes of pressure even if minor modifications are introduced, but it is not applicable for porous propellants.

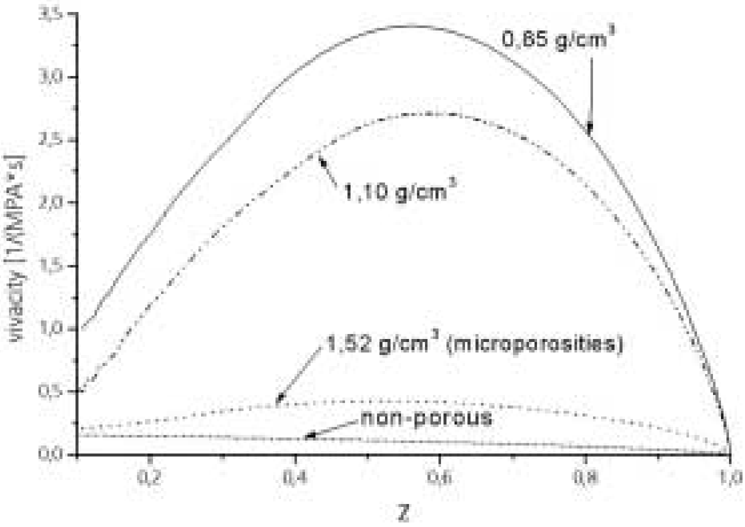

Figure 3: Influence of density changes on vivacity,
closed vessel experiments in 106 ml vessel, loading density 0,2 g/cm3.

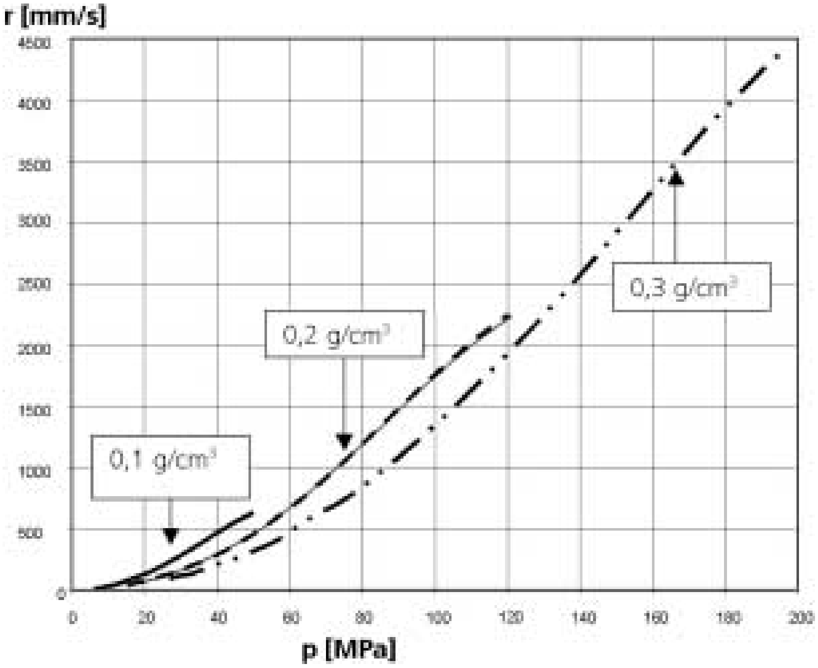

Figure 4: Loading density influence on the effective linear burning rate on a porous charge.

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Since the linear burning rate is a major input to the simulation of the interior ballistic behaviour of gun propellants which is obtained by closed vessel experiments or gun firings [8,9], for foamed propellants modifications of Vieille's law or new models have to be developed. A short description of a phenomenological model valid to describe the burning characteristics of porous charges and simulation results are presented in the next section.

MODEL: SIMULATION RESULTS AND BURNING CHARACTERISTICS

The burning behaviour of porous foamed propellants deviates from Vieille's law. Some theoretical approaches assume that hot gases of the flame penetrate the porous solid. The gases generate hot spots in the propellant pores which evolve to (quasi) spherical burning zones. This leads to an increased burning surface and therefore in consequence to a higher burning rate. Also the effect of stand-off distances of the flame which depend on pressure has to be taken into account [5].

The implementation of these effects to interior ballistic calculations at Fraunhofer ICT is obtained by a phenomenological model using the concept of cellular automates [4,6]. It enables to apply the linear burning rate to the enlarging pores of burning energetic materials. 3 dimensional form functions are obtained by a formal procedure. In addition on the basis of the Nobel-Abel-equation the adiabatic pressure rise in a closed vessel is simulated. Closed vessel tests with non-porous and porous propellants were used to modify the model parameters.

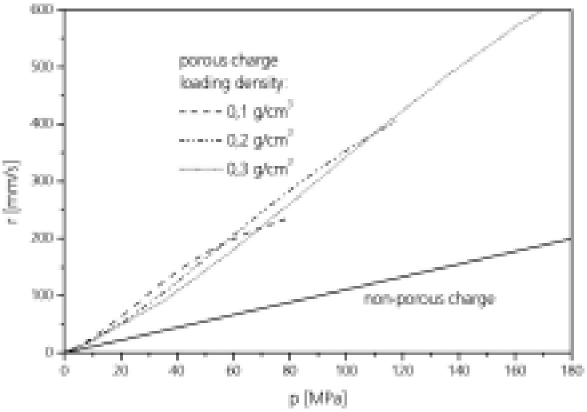

Figure 5: Simulation of the loading density influence on linear burning rate.

Input parameters for the calculations are data of ICT-Thermodynamic Code [10] (mean molecular weight of the generated gases, covolume, density, flame temperature), Vieille's law results of non-porous propellants, charge geometry, consideration of inner structure, assumptions on gas penetration and experiment parameters like loading density, bomb volume and ambient temperature.

As an example the theoretical calculations of the linear burning rate are shown in dependence on loading density for a porous and non-porous charge (Fig. 5). With increasing porosity the burning rates rise to the same quantity as presented in Fig. 4. In Fig. 6 and Fig. 7 the influence of total pore volume and of pore diameter changes on dynamic vivacity is demonstrated. In both cases the porous structure was simulated by an simplified ensemble of pores (see Fig. 2) to mark the effects:

In Fig. 6 the density of the charge was changed from a compact charge to a charge including pores with a total volume of up to 40% of the volume of the non-porous charge, that means that the density is decreased down to 60%. In this case the diameter of all pores was kept constant (0.25 mm). In Fig. 7 the total pore volume was identical for all calculations (40%) (i.e. the density was kept constant) but the pore diameter was varied.

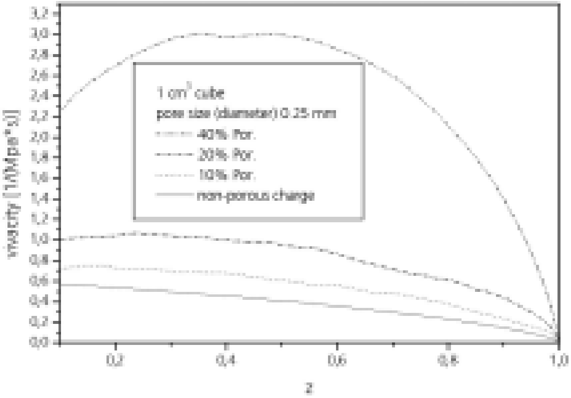

Figure 6: Simulation, influence of total pore volume on vivacity.

Both diagrams mark the massive influence not only of density but also of pore size distribution on the burning characteristics and gave a graphic explanation of microporosity effects.

A factor that makes quantitative predictions complicated is the strong influence of penetration depth of interaction on the pressure rise (Fig. 8). In contrast to standard propellants the reaction zone is enlarged for porous propellants. Hot spots and hot gases of the flame penetrating the pores lead to ignition and combustion not only of the actual outer surface but also in the depth of the porous charge. Burning interruption experiments show that reaction zones could have depths in the order of 100 µm. Future quantitative predictions of interior ballistic behaviour of porous charges require experimental input and model adaptations in this area. The work is in progress.

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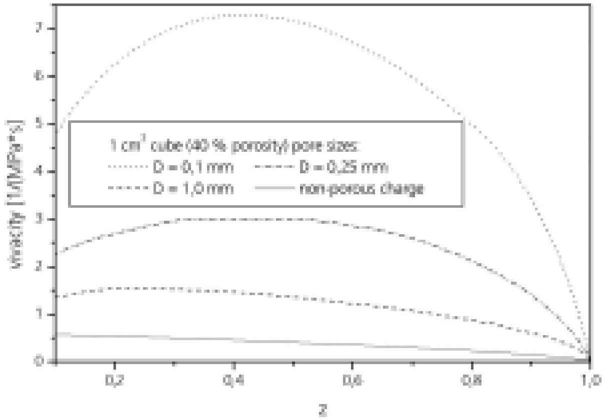

Figure 7: Simulation, influence of pore size (D = diameter) on vivacity.

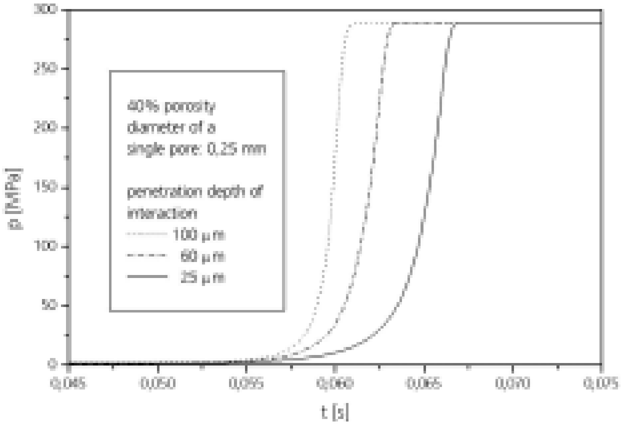

Figure 8: Simulation of the influence of interaction penetration depth on pressure rise.

CONCLUSIONS

Explicit consideration of the internal structure of porous charges in our interior ballistic model enables the qualitative description of the burning phenomena found in experiments. This comprise changes of density, formulation, geometry, pore size and pore distribution but also influences of experimental parameters like loading density. On this basis predictions on the special interior ballistic behaviour of geometrically complex porous charges are possible.

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