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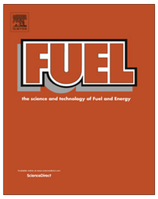

Effects of grain size and temperature of double base solid propellants on internal ballistics performance

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HIGHLIGHTS

- A double base solid propellant was tested.
- Experiments were carried out in laboratory conditions and in a shooting range.
- Effects of grain size and temperature on pressure and bullet velocity were studied.
- Burn rates were determined as functions of grain size, temperature and pressure.

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ABSTRACT

A conventional bullet or projectile driven by solid fuels accelerates in the barrel and reaches certain muzzle velocity, spin and propulsion energies. Combustion characteristics of solid fuels are the most important factor affecting bullet performance and maximum range. In this work, double base solid propellants of spherical geometry within the ranges of 300–425, 425–500, 500–600, 600–710 and 710–850 μm in diameter and temperatures of −60, −40, −20, 0, 20, 40 and 60 °C, were investigated in terms of the effects of grain size and temperature on burn rate, internal barrel pressure and bullet velocity. Solid fuel properties such as fuel heat of combustion, density, combustion temperature, particle size and mass were measured. In a constant volume chamber, burn rate was measured for each fuel sample at different pressure and temperature. In addition, cartridges of 7.62 mm in diameter were made using sample solid fuels, and shooting tests were carried out with a special test barrel. In the tests, strains along the barrel were determined using strain gauges and the muzzle exit velocity of the bullet was measured with a doppler radar for calibrations. It was seen that the increase of fuel temperature and decrease of particle size increased burn rate, internal barrel pressure and bullet velocity.

1. Introduction

Bullets in conventional weapon systems get their propulsion and spin energies while being inside the barrel and only from solid propellant fuels or gun powders. Thus, one of the most important design parameters that affect bullet performance and range is burn rate of solid fuel or gun propellant. Burn rate depends on many factors such as combustion chamber pressure, geometry and temperature of the fuel, high energy substances, combustion sensitivity, chemical substances regulating the burn rate, oxidizer amount and the energy of the igniter. In solid propellants, combustion starts at the outer surface of the propellant and moves along the length of the central core, with the burning surface expanding radially outward [1]. The rate of change of solid propellant as burn rate can be expressed as [2–4]:

$$w\frac{dr}{dt} = kTP^n \qquad (1)$$

where r is burn rate (mm/s), T is temperature, k and n are experimental constants, w is the distance between burning surfaces and P is pressure (kPa).

Although chemical and physical events during the combustion of solid propellants are very complicated and not known to the fullest extent, advanced combustion models are capable of modeling flame structure, gas phases and other products, mathematically [1–4].

Solid propellants burn without the need of an external oxidizer because they contain the fuel and oxidizer together in their structures. Propellant grains, based on their combustion surfaces, can be classified as regressive, neutral and progressive burning. If there is

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Table 1
Properties of double base propellant samples.

Adiabatic flame temperature (K)	Heat of combustion (cal/g)	Density (g/cm^3)	Combustion constant (k)	Pressure exponent (n)
2570	960	1.58	0.00086	0.63

Grain size (μm)	300–425	425–500	500–600	600–710	710–850
k/w	0.36	0.46	0.55	0.65	0.78

a central core, it is usually a neutral burning grain. If the grain is cylindrical, spherical and cubical, it is regressive burning. And, multi-perforated grains are usually progressive burning [5].

Temperature of the combustion chamber is one of the important parameters affecting the burn rate. The burn rate may also change based on the pressure of the medium, solid propellant compositions, the ratio of ammonium perchlorate (AP) and propellant grain size. It was seen that the burn rate increased with respect to pressure for different compositions of AP and solid propellant [6]. Under different pressures, solid propellants showed different combustion behaviors and burn rates [7]. Also, as initial temperature and pressure of the combustion chamber increased, the burn rate increased. With that, as the fuel temperature increased, the end pressure also increased which shortened the combustion duration [8]. There are also studies that have investigated burn rate, combustion surface and pressure relations in a wide range of pressures [9,10] and found that burn rate increased not only by increasing pressure but also combustion surface area.

Solid fuel burn rate is measured by several methods. One method uses a constant pressure, nitrogen environment. This method is usually very expensive and time-consuming. Another is the ultrasonic method that uses constant volume combustion and determined burn rate based on gathered data from high frequency sound waves [7]. This technique allows for the measurement of the instantaneous thickness of the solid fuel. Ultrasonic signal and pressure measurements require simultaneous analysis of a wide range of pressures during the solid combustion. Strand burners are also used to measure pressure and burn rate, as well as, to predict burn rate from pressure measurements [11].

In this work, a double base propellant (85% nitrocellulose and 15% nitroglycerine) with spherical grains was used and burn rate was determined in a laboratory setting and at a shooting range. Grains were sieved to have certain ranges of grain sizes as 300–425, 425–500, 500–600, 600–710 and 710–850 μm. Burn rate was measured for different grain sizes at temperatures of −60, −40, −20, 0, 20, 40 and 60 °C. For the same propellants, tests were performed in a shooting range using a NATO-standard 7.62 mm weapon. Combustion temperature that changes as a function of pressure and temperature was calculated using a method available in the literature [4]. Decrease of grain size and increase of temperature showed to increase burn rate, maximum pressure and bullet velocity.

2. Experimental study and results

2.1. Propellant and grain properties

Experiments were performed in two stages: in laboratory conditions and at a shooting range. The same test samples were used for both experimental studies. The double base propellant (85% nitrocellulose and 15% nitroglycerin) and spherical grains were taken from the same manufacturing line. For each propellant group, the heat of combustion was determined in a calorimeter of 1 g capacity with 3 samples, and the average was taken. Properties of the double base propellant are shown in Table 1.

Solid propellants were sieved to create dimensional groups of 300–425, 425–500, 500–600, 600–710 and 710–850 μm in diameter. For the assortment process of the grains, six stacked sieves were used below one another. The top sieve had a diameter of 850 μm and the rest of the sieves had diameters of 710, 600, 500, 425 and 300 μm. Grain samples were put inside the top sieve of the diameter of 850 μm and the assortment process was completed by shaking the sieves. In this way, while the grains of diameters larger than 850 μm stayed in the top sieve, the smaller grains dropped to the next sieve until every grain found its respective sieve based on its diameter. The elimination of the grains was carried out for all diameters and test samples were prepared. In order to get high quality data from the shooting tests, control

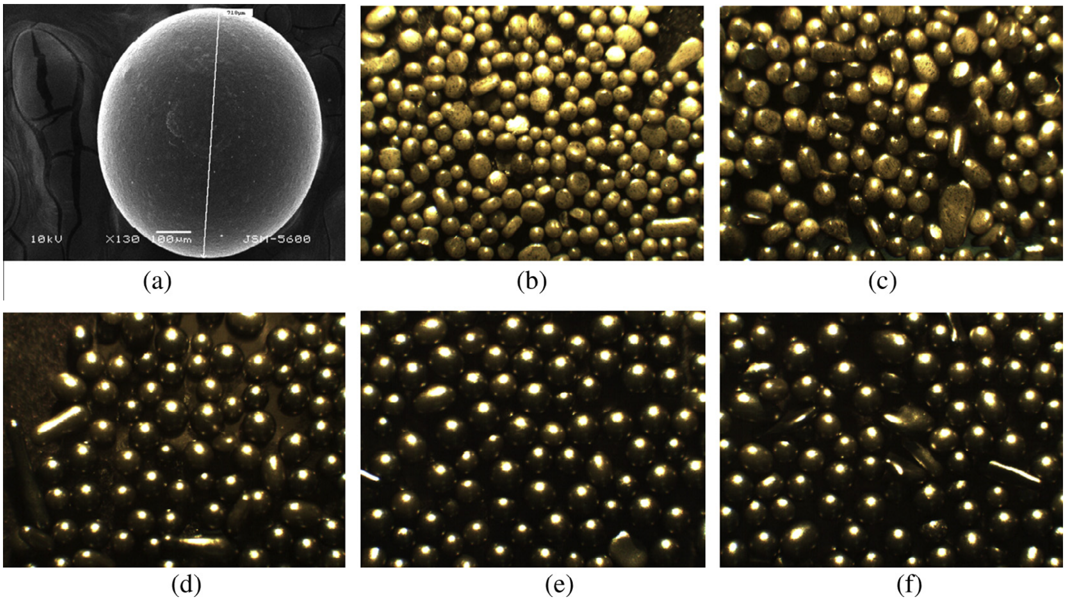

Fig. 1. Zoomed images of the spherical grains. (a) 130× zoomed image, and 10× zoomed images of (b) 300–425 μm, (c) 425–500 μm, (d) 500–600 μm, (e) 600–710 μm, and (f) 710–850 μm.