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Shrinkage in Propellant Manufactured by Solvent Process

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ABSTRACT

The propellant manufacturers select the dimensions of die-pin for extrusion of dough by trial and error method based on their experience. This paper presents a general equation applicable for any propellant composition processed by solvent process, in any shape, i.e., cord, monotubular or the multitubular. To illustrate the relationship, calculation for outer radius for a few typical single-base propellants is given.

1. INTRODUCTION

In the solvent process for manufacture of propellant, nitrocellulose (NC) is gelatinised to desired consistency with the help of the solvent. The solvent is removed by drying process after the extrusion of gelatinised mass (dough). In this process, as the solvent leaves the system—the solid ingredients (NC, etc), non-volatile materials (plasticisers, modifiers, etc), and the volatile solvents—the dimensions of extruded material shrink.

By and large, all the propellant manufacturers are required to manufacture the propellants with a given finished dimensions and density. As such, they are supposed to extrude the dough at such dimensions which after removal of solvent, i.e., after shrinkage, will conform to rigid physical specifications. Even though the art of propellant manufacture is more than a century old (Kays[1], Urbanski[2] and Ball[3] describe the state-of-art adequately), most of the propellant manufacturers select the

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dimensions of die-pin for extrusion of dough by trial and error method based on their experiences. This paper presents an alternative approach to the problem of die-pin dimensions through theoretical calculations.

1.1 Theory

Let ΣV_s be the summation of individual volumes of non-volatile components, ΣV_l be the summation of individual volumes of volatile solvent taken for kneading, ΣM_s be the summation of individual masses of non-volatile components, and ΣM_l be the summation of individual masses of volatile solvents taken for kneading.

The calculated density of dry propellant is given by

$$d = \frac{\Sigma M_s}{\Sigma V_s} \tag{1}$$

The calculated density of green (wet) propellant is given by

$$\frac{\Sigma (M_s + M_l)}{\Sigma (V_s + V_l)} \tag{2}$$

and the ratio of dry mass to wet mass is given by

$$A = \frac{\Sigma M_s}{\Sigma (M_s + M_l)} \tag{3}$$

If W is the mass of unit length of green propellant, then the mass of propellant after drying is equal to WA. But the mass of unit length of dried propellant is given by

$$\pi(R^2 - nR_1^2)\left(\frac{100-p}{100}\right) d \tag{4}$$

where p is the per cent porosity, R is the outer radius, R_1 the inner radius, and n the number of holes.

That is

$$\frac{\pi(100-p)}{100}\, d \;\; (R^2 - nR_1^2) \;=\; WA \tag{5}$$

or

$$R = \left(\frac{100\, WA}{\pi\, d\, (100-p)} + nR_1^2 \right)^{1/2} \tag{6}$$

Under the extrusion conditions, let the flow of dough (green material) be assumed to be a streamlined one. Then the diameter of strands formed during the extrusion will be the same as the diameter of the die hole. This gives the mass of unit length of propellant (green) as

$$W = \pi(r_{OD}^2 - nr_{ID}^2)\ \Sigma\,(M_s + M_l)\ /\ \Sigma\,(V_s + V_l)$$

where r_{OD} is the radius of the die hole, and r_{ID} is the radius of pins.

Substituting the values of W and A in Eqn. (5) we get

$$R = \left[\frac{100\,\pi\,(r_{OD}^2 - nr_{ID}^2)\ \dfrac{\Sigma\,(M_s + M_l)\,\Sigma\,M_s}{\Sigma\,(V_s + M_l)\ \Sigma\,(M_s + M_l)}}{\pi\,d\,(100 - p)} + nR_1^2 \right]^{1/2}$$

$$= \left(\frac{100\,(r_{OD}^2 - nr_{ID}^2)\ \Sigma\,M_s}{d(100-p)\ \Sigma\,(V_s + V_l)} + nR_1^2 \right)^{1/2} \quad (7)$$

Substituting the value of d from Eqn. (1)

$$R = \left(\frac{100\,(r_{OD}^2 - nr_{ID}^2)\ \Sigma\,M_s}{\dfrac{\Sigma\,M_s}{\Sigma\,V_s}\ (100 - p)\ \Sigma\,(V_s + V_l)} + nR_1^2 \right)^{1/2}$$

$$= \left(\frac{100\,(r_{OD}^2 - nr_{ID}^2)\ \Sigma\,V_s}{(100-p)\ \Sigma\,(V_s + V_l)} + nR_1^2 \right)^{1/2} \quad (8)$$

In Eqn. (8) terms R and R_1 (dimensions of propellant) or r_{OD} and r_{ID} (dimensions of die-pin) are unknown. In order to solve the above equation, approximation is used as follows.

In comparison to R, both the radius R_1 and r_{ID} are very small and hence for first order computation it is assumed that

$$R_1 \approx r_{ID}$$

Substituting the value of R_1 in Eqn.(8)

$$R = \left(\frac{100\,(r_{OD}^2 - nr_{ID}^2)\ \Sigma\,V_s}{(100-p)\ \Sigma\,(V_s + V_l)} + nr_{ID}^2 \right)^{1/2} \quad (9)$$

or

$$R = \left(\frac{100\,(r_{OD}^2 - nR_l^2\ \Sigma\, V_s}{(100-p)\ \Sigma\,(V_s + V_l)} + nR_l^2 \right)^{1/2} \tag{10}$$

Equations (9) and (10) give a direct relationship between the radius (outer) of propellant under consideration and the process conditions (dimensions of die-pin and solvents taken for gelatinisation), and can be used for calculating the shrinkage and die diameters.

Since, in the proposed relationship, ΣV_s represents the volumes of non-volatile components in a propellant composition, this relationship is valid for all types of propellant compositions. Further one can use this for cord, monotubular or the multitubular shapes by giving an appropriate value to n, i.e., n is 0 for cord, n is 1 for monotubular, n is 7 for heptatubular, and so on.

2. EXAMPLES

The following examples illustrate the calculation for outer radius for a few typical single-base propellant compositions.

2.1 Example 1

Let the composition of dough be as shown in Table 1. The dough is extruded through a die-pin assembly 6.88/ 3.69/ 0.73/ 0.73 mm in heptatubular shape, (i.e., n is 7). Porosity of the propellant after drying is 2 per cent (i.e., P is 2). Also $\Sigma V_s = 61.31$ l, and $\Sigma(V_s + V_l) = 143.44$ l. Substituting these values in Eqn. (9) , we get $R = 2.38$ mm. This compares favourably with the experimentally found value of 2.36 mm.

Table 1. Composition of the wet propellant mass for example 1

Ingredients	Density[4] (g/cc)	Mass* (kg)	Voume (l)
Nitrocellulose (dry mass)	1.66	88.4	53.25
Diphenylamine	1.16	0.98	0.845
Dibutylphthalate	1.04	1.47	1.41
Dinitrotoluene	1.32	7.37	5.58
Potassium nitrate	2.66	0.60	0.225
Ether	0.71	35.5	50.0
Alcohol and water	0.80	25.70	32.13

* Composition of dough (parts by mass)

2.2 Example 2

The composition of dough in this example is shown in Table 2. The dough is extruded through a die-pin 1.95/ 0.3 mm in monotubular shape (i.e., n is 1). Porosity of propellant after drying is 4 per cent (i.e., P is 4). Also $\Sigma V_s = 65$ l, and $\Sigma(V_s + V_1) = 199.25$ l. Substituting these values in Eqn. (9), we get $R = 0.58$ mm which compares with the experimental value of 0.62 mm.

Table 2. Composition of the dough for example 2

Ingredients	Composition (parts by mass)	Density (g/cc)	Mass (kg)	Volume (l)
Nitrocellulose	98.0	1.66	105.0	63.25
Diphenylamine	0.5	1.16	0.54	0.46
Centralite	0.5	1.12	0.54	0.48
Potassium bi-tartrate	1.0	1.96	1.60	0.81
Ether	51.69	0.71	55.38	78.0
Alcohol and water	42.0	0.8	45.0	56.25

2.3 Example 3

Let the composition of dough be as shown in Table 3. The dough is extruded through a die 1.3 mm in cord shape (i.e., n is 0). Porosity of propellant after drying is 4 per cent (i.e., P is 4). Also $\Sigma V_s = 89$ l, and $\Sigma(V_s + V_1) = 219$ l. Substituting the values in Eqn. (9), we get $R = 0.42$ mm, which compares with the experimental value of 0.43 mm.

Table 3. Composition of the dough for example 3

Components	Composition (parts by mass)	Density (g/cc)	Mass (kg)	Volume (l)
Nitrocellulose	91	1.66	136.53	82.25
Diethylphthalate	2	1.12	2.90	–
Carbamite	2	1.12	2.90	5.18
Cuprous oxide	1.5	6.0	2.2	0.37
Leadphthalate	3	6.8	4.35	0.64
Potassium nitrate	1	2.1	1.18	0.56
Ether	36	0.71	54.0	76.0
Alcohol and water	28.8	0.8	43.2	54.0

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