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Preparation and Characterization of Some Selected Double Base Propellant Formulations

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Abstract:
Effect of energetic base (NC and NG) variation and plasticizer change were investigated in this work. The gradual increase of (NG %) at the expense of (NC %) increased the burning rate up to 40%, whereas the maximum stress (σm) value has been reduced gradually. No significant change could be detected in density, heat of explosion and ignition temperature. The plasticizer content could be decrease from 11% to 9 % at constant NG percentage (35%) without any significant effect on either density or ignition temperature. On the other hand these variations cause a slight effect on stress and the strain. The young's modulus dropped from 438 to 207 and the hardness decreases from 73 to 66 Shore A. whereas the burning rate has been increased by about 26%. DB4 formulation composed of 48% NC, 35% NG, 9.5% inert plasticizer and 7.5% other additives was satisfying the criteria of base bleed where its maximum stress was 29 Kg_f/cm^2 and strain was found to be about 39%.

Keywords: *Solid propellant, double base propellants, energetic base, burning rate and mechanical properties*

1. Introduction

Artillery is certainly, and will continue to be, one of the main distractive forces and powerful firing means against different types of enemy targets especially long range of artillery projectiles depending on many factors, some of which are related to the weapon and others to the projectile itself [i].The normal burning rate of these propellants is about 1 mm/sec are aimed as desirable burning rates at ambient pressure. Their mechanical properties of the propellant in the range of – 40 to +60°C [ii-iii] must be sufficient to avoid the formation of cracks due to the high acceleration of the projectile, so the grain must have high flexibility and maximum strain [iv]. Mechanical characteristics mainly depend on three factors which are binder, particle size of filler and adhesion between its particles and the binder. They vary with temperature and stress rate or strain in such a way that time temperature equivalence has been determined for each type of binder. Many researchers are concerned about developing the reduced smoke base bleed propellant because smoke may reveal the location and the expected environmental bad effects due to emission of HCl gases in exhaust plume and also affects the nozzle because of slag or erosion, all exhaust plumes generally interfere with the transmission of radio and radar signals that must pass through the plume in the process of guidance or communication it is imperative to investigate the use of the so-called “clean burning propellants”, which eliminate chlorine as an ingredient [v-viii]. Smoke and flame phenomena of propellants may be sub-divided into the occurrence of primary smoke, secondary smoke and plume after-burning, the latter giving rise to a visible flame [ix]. Primary smoke consists of liquid and solid particles mixture that is ejected with the combustion gases. Any compound such as ballistic modifiers, flash suppressants, mineral elements or metallic fuel solids included in a propellant formulation that contains these elements of the particle matter described above, may give rise to the formation of primary smoke particles [x-xi]. DB propellant is one of the oldest propellant families, both oxidizer and fuel belongs to the same molecule. Where, nitro cellulose (NC) and NG bring together the C, H and O necessary for the reaction [xii-xiii]. In this work DB base bleed propellant formulations are prepared to achieve the parallel need of no smoke in exhaust plume as they are free from HCl in the exhaust, having mechanical and performance parameters that meet with base bleed propellant parameters as shown in table (1).

Propellant properties	
Stress at maximum strain	Min. 10.5 Kg_f/cm^2
Elongation	Min. 30%
Burning rate	0.9 – 1.5 mm/s
Density	Min. 1.5 g/cm^3

Table 1: Double base propellant controlling factors

2. Thermo-chemical Calculations

Thermo-chemical calculations have been used with considerable success as a fast and effective tool to investigate the characteristics of different types of propellant formulations and to minimize the required experiments of these calculations are given in Table (2) the performance has been improved by increasing the NG content according to these calculations [xiv-xv].

Results of formulations illustrated in table indicate that as the percentage of NC increases at the expense of NG, the performance characteristics decrease, the density is increased as the density of NC is greater than NG. Also as the percentage of plasticizer increases at the expense of NG, the performance characteristics decrease and the density also decreases. This is because NG density is greater than that of the plasticizer. Results of thermo-chemical calculations are very important for propellant compositions that are candidate for preparation and expected to give the required performance of the needed application.

Ingredients / Formula		DB1	DB2	DB3	DB4	DB5
Energetic Base	NC	53.5	49.5	46.5	48	48.5
	NG	28	32	35	35	35
plasticizer	DBP	11	11	11	9.5	9
Additives		7.5	7.5	7.5	7.5	7.5
Density (g/cm^3)		1.560	1.545	1.533	1.544	1.547
O_b		- 48.68	- 47.03	- 45.79	- 42.99	- 42.06
T_f (K)		1894	1953	2032	2135	2169
C* (m/s)		1270	1292	1307	1330	1337

Table 2: Results of Thermochemical Calculations

3. Experimental

3.1. Preparation of the Samples

The role of the manufacturing process is to ensure the transformation of the raw materials into a finished product which is as close as possible to desired grain shape and size. Therefore, the manufacturing process provides for a number of essential functions, such as the homogenization of the product, its gelatinization, and shape. The procedures of solvent less extruded double base being with homogenization of the wet paste through which mixing and blending take place for 30 minutes after loading the blender with the wet paste. Humidity is detected through three samples taken from the paste after the end of blending operation. Kneading phase for the wet paste run for five minutes before adding the dry chemicals and then run for 45 minutes. The paste is aged in plastic boxes for 24 hours. Rolling phase begins with raising the roller temperature to be 75-80oC then pass the past two times through them. The rolling operation lasts for 8-12 times until gelatinization then cutting takes place into square parts of 20×20cm with the knife working with air pressure and its temperature is kept between 80-90oC. Feed the equipment with the 20×20cm pieces to be cut into smaller and fine pieces. Granulation phase takes place, and then drying process until humidity reaches 0.15%. At last formation of the propellant rods through the extruder, to guarantee good stability of the dimensions, precise heat control is necessary to maintain the die at a uniform temperature. Annealing of the rods took place at 60oC for 6 hours and left in the annealing chamber until the temperature reaches room temperature then turning to the final length takes place. The propellant rods shall be inhibited then final turning takes place.

3.2. Characterization of the Prepared Samples

The prepared samples are tested through X- ray unit to assess the inner homogeneity, cracks, air bubbles, porosity and foreign matters. The heat of explosion (HEX) of the propellant is measured as the heat released when a material is ignited and burned [xvi-xvii] in a PARR 6200 bomb calorimeter in an inert atmosphere (nitrogen gas). The spontaneous ignition is tested by progressive heating regularly increasing the temperature by 5oC every minute this test show that the maximum temperature to which the propellant can be subjected during its manufacture and use. The propellant density is measured at 20^oC using ordinary Pycknometer (density crucible) and silicon oil. The samples of the propellant used to measure the density are being cut in regular and equal shape. The stress-strain relation and modulus of elasticity for the prepared samples is measured by the aid of Zwick (model 1487) testing machine with cross-head speed of 50 mm/s at 25^oC. Burning rate is determined by firing on static benches using certain nozzle which secure the range of operating pressure. The pressure and time history is recorded for each test and the ballistic performance calculated.

4. Results and Discussions

4.1. X- Ray inspection

Base bleed samples are successfully prepared, X-ray inspection is done, no surface anomalies are observed, the inner homogeneity is good, and no cracks, air bubbles, porosity and foreign matters are found.

4.2. Effect of Energetic Base Variation on the Sample Characteristics

Three compositions DB1, DB2 and DB3 found in table (2) are prepared to investigate the effect of energetic base variation on base bleed properties. Energetic base percentage change affect stress, strain, young's modulus, and hardness are illustrated in figure (1) and figure (2).

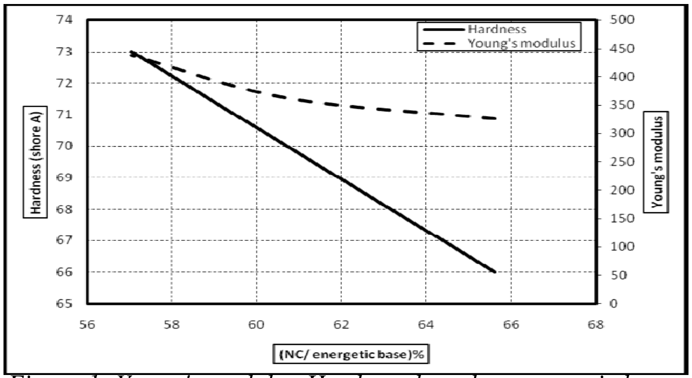

Figure 1: Young's modulus-Hardness based on energetic base variation

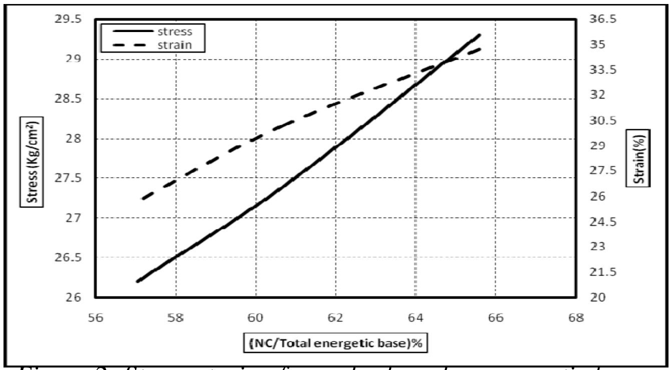

Figure 2: Stress-strain of samples based on energetic base variation

Also figures (3) and figures (4) illustrate heat of explosion and burning rate of the same samples which clears that the increase of NG percentage at the expense of NC is not large enough to make a significant change in density, heat of explosion and ignition temperature as the change in overall calorific value resulting is too small to make touchable change, also the three samples DB1, DB2 and DB3 satisfy the values of BB applications. The increase of (NG %) gradually increases the burning rate by (28%) and (40%) for DB2 and DB3 respectively. The gradual increase of the maximum stress (σm) and hardness values is due to the gradual reduction of NC macromolecules amount and mobility, together the strain also increases with a gradual decrease of young's modulus (E) due to the increase of NG amount increase which acts as a plasticizer and also NC fibers retains its mechanical properties to the propellant, the three samples offer a good values of the mechanical properties satisfying the minimum values required.

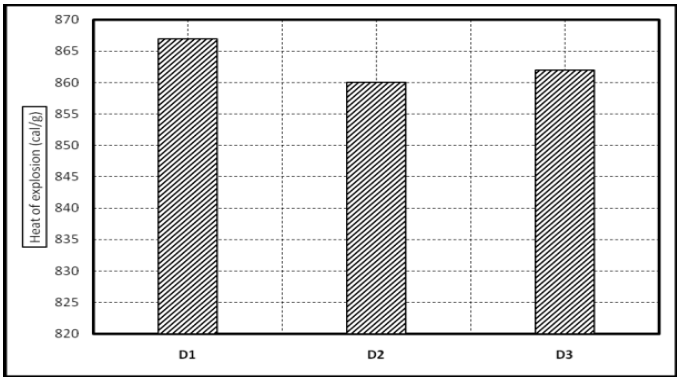

Figure 3: Heat of explosion based on energetic base variation

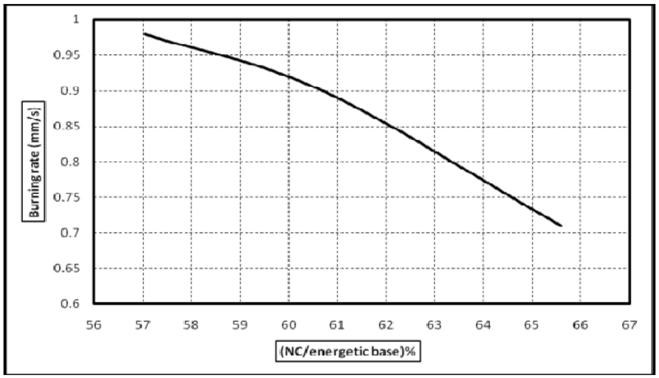

Figure 4: Burning rate of samples based on energetic base variation

4.3. Effect of the Plasticizer Content on the Sample Characteristics

Three compositions DB3, DB4 and DB5 found in table (2) are prepared to investigate the effect of plasticizer percentage variation on base bleed properties. Plasticizer percentage change has an effect on stress, strain, young's modulus, and hardness is illustrated in figure (5) and figure (6). Also figures (7) and figure (8) illustrate heat of combustion and burning rate of the same samples which clear that increasing NC content from 46.5 - 48.5 % and decreasing the plasticizer value 11 – 9 % in DB formulations prepared with constant NG percentage (35%) and no change in the content of other additives in the three formulations one can see, that these variations has no significant effect on some parameters of prepared formula including density and ignition temperature. On the other hand, these variations cause a slight change in the values of stress, strain and a pronounced change down words in the values of young's modulus from 438 to 207 and the hardness decreases from 73 to 66 shore A and the heat of explosion increases from 830 to 862 cal/g due to the increase in the net value of oxygen balance due to decreasing of plasticizer percentage (inert gelatinize had low calorific value) affecting the value of the whole matrix. The decrease of plasticizer di-butuyl phthalate (%) gradually increases the burning rate by (8%) and (26%) for DB4 and DB5 respectively. Sample DB4 has the best optimization as its density, heat of explosion, ignition temperature and burning rate comply with the required properties also for the mechanical properties also offer high stress, high hardness and high strain with low values of young's modulus.

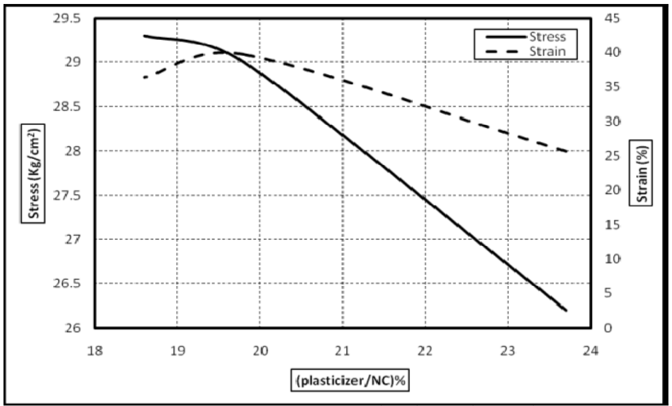

Figure 5: Stress-Strain of samples based on plasticizer variation

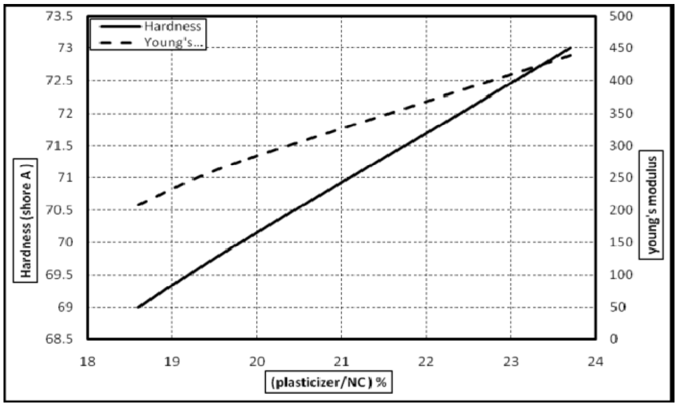

Figure 6: Hardness-Young's modulus based on plasticizer variation

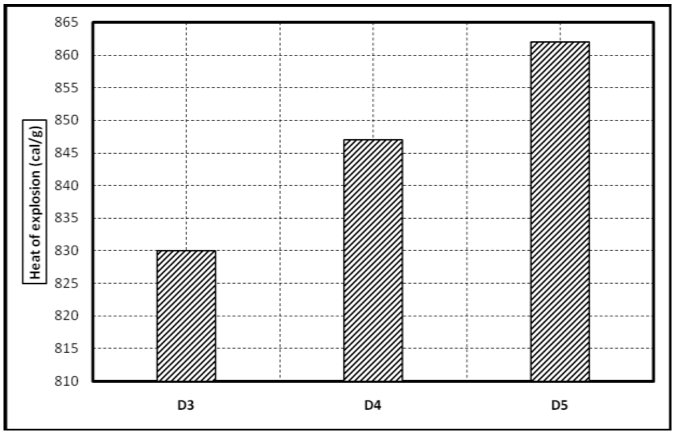

Figure 7: Heat of explosion based on plasticizer percentage variation

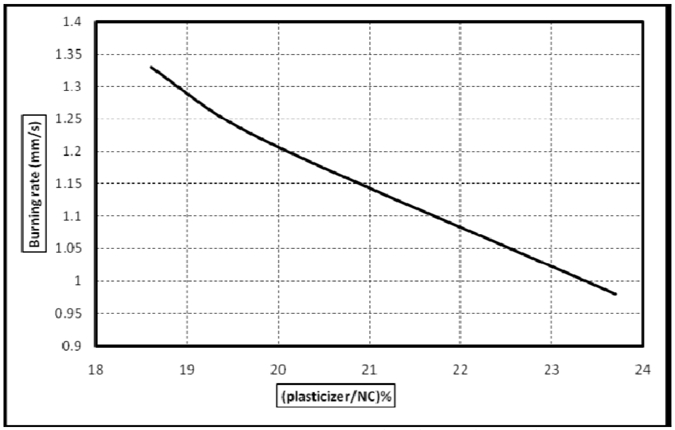

Figure 8: Burning rate of samples based on plasticizer percentage variation

5. Conclusions

Results of thermo-chemical calculations are essential for choosing propellant formulations that are candidate for a given practical application to minimize many costly experiments which are used to evaluate the performance and properties of new propellant formulations. Any increase in NG in the formulation consequently increases the burning rate. Decrease in NC % increases the stress due to the decrease in NC macromolecules mobility. The Heat of explosion increases with the decrease of inert plasticizer % as the increase of net calorific value of the formulation which intern increase the burning rate. The decrease of inert plasticizer does not significantly affect both density and ignition temperature. Double base propellant sample DB4 satisfies all the criteria of propellants applied in this work and also it free from signature which may reveal the location.

6. References

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