Low Signature Advanced Base Bleed Grains

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***Abstract*—** Base bleed still one of the effective methods to extend the projectile range as it decreases the base drag which composes about 50% of the total drags acting on the projectile. Also, low signature propellants are very important in order not to reveal the gun position. So, various compositions are prepared to optimize the superior mechanical properties the propellant must achieve together with low signature. rocket propellants containing two bonding agents were studied Tris-1- (2-Methyl Aziridinyl) Phosphine Oxide (MAPO) and mixed MAT4 (which is a mixture of MAPO, adipic acid and tartaric acid) give us stress 11.7 Kg/cm2 and strain of 16.3 %, then curing ratio starting from 0.97 to 0.7 are also studied giving the optimum mechanical properties at 0.83 where the strain reached about 34%. Primary smoke is not affected by adding 7% of hexogen (RDX) instead of ammonium perchlorate (AP) but the secondary smoke is decreased by about 40%, while by adding 5% magnesium (Mg) secondary smoke is decreases by about 75% but the primary smoke is dramatically increased.

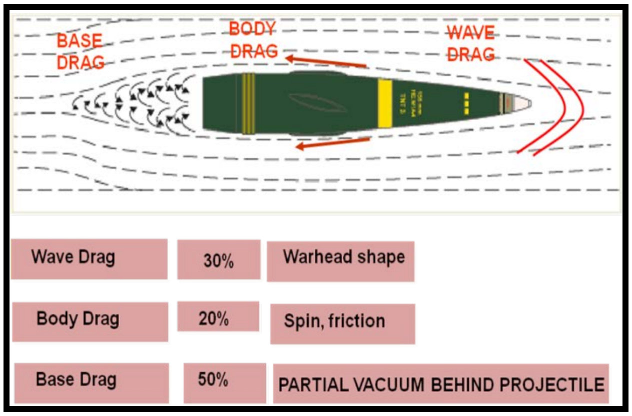
Index Terms— Base Bleed, Low Signature, Composite Propellants, Mechanical Properties, DSC, Heat of explosion, Burning rate

1 INTRODUCTION

Range extension of artillery projectiles has always been basic requirement of the user in order to shoot the enemy targets at longer distances. There are many methods to extend the projectile range which may be related to the weapon or the projectile itself. Base bleed unit is one of the devices used to decrease air resistance during projectile flight in air and, consequently, increase the range [1]. Base bleed (BB) decreases the base drag component illustrated in figure (1) which represents about 50% of the total drag at supersonic velocities and resulting from the formation of the under pressure region behind the projectile by filling up the wake zone with gases escaping from the gas generator, and thus increase the base pressure. Increased base pressure reduces the base drag and gives increased shooting distance for the projectile [2]. Values of burning rate around 1 mm/sec for base bleed grain are aimed as desirable burning rates at ambient pressure [3]. The standard of the mechanical properties of the propellant in the range of -40 to +54°C had to reach values for maximum stress to minimum 10.5 Kgf /cm^2 and maximum Strain to be of minimum 30% which were sufficient to avoid the formation of cracks or even destruction of the propellant charge resulting from the shock experienced upon firing of the cannon and the heat of explosion is found to be around 820 cal/g [4,5,6].

Due to the high acceleration of the projectile longitudinal strains are developed in the bore of the grain. The propellant must therefore have a high flexibility and ultimate tensile strain limit. Mechanical characteristics mainly depend on the binder but also on the particle size and on the adhesion between particles and 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 were concerned about developing the reduced smoke propellant because smoke may reveal the gun location and the expected environmental bad effects due to emission of HCl gases in exhaust plume [7]. It was found that the presences of RDX, HMX, Mg, NaNO3 and NH4NO3 in many composite propellant formulations decrease the smoke and has no effect on curability and secure propellant parameters in the needed ranges according to the controlling factors shown in table (1).

The smoke and flame phenomena of propellants may be subdivided into the occurrence of primary smoke, secondary smoke and plume after-burning, the latter giving rise to a visible flame [8]. Primary smoke consists of liquid and solid particles mixture that is ejected with the combustion gases.



Wave Drag	30%	Warhead shape
Body Drag	20%	Spin, friction
Base Drag	50%	PARTIAL VACUUM BEHIND PROJECTILE

Fig. 1. Types of Drag Forces

TABLE (1) BASE BLEED CONTROLLING FACTORS

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

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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 [7].Both the occurrences of secondary smoke and plume after-burning may be related to the combustion gases of propellants (CO, CO_2, H_2, H_2O, N_2) and in the case of propellants containing AP, hydrochloric acid (HCl) gas was also formed [8].Smoke may reveal the gun location and allow the projectile to be located in flight 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 [9]. In order to overcome the environmental problems and to avoid the detection of trajectory of the ballistic missile, it is imperative to investigate the use of the so-called "clean burning propellants", which eliminates chlorine as an ingredient [10,11].These include Low HCl scavenged formulations, HCl neutralized propellant formulations, Low HCl formulations oxidized with a combination of AN and AP (with or without an HCl scavenger), Chlorine-free formulations. Each of these propellant formulations has its own advantages and disadvantages depending upon the chemistry involved and the physical properties of the materials used for base bleed formulations [12,13].

In this work composite solid rocket propellant formulations were prepared to achieve the parallel need of castable low smoke in exhaust plume having mechanical and performance parameters that meet with base bleed propellant parameters.

2 EXPERMENTAL

2.1 RAW MATERIALS

All the raw materials and their sources, used in this work were pure and did not need any further purification; their labelled specifications are mentioned and illustrated in table (2).

TABLE (2) PROPERTIES OF RAW MATERIALS

Materials Parameters	Summary formula	M.p (^{o}C)	Mw g/mol	density g/cm^3	ΔH_f cal/mol
APc	NH_4ClO_4	235	117	1.95	-70.69
RDX	$C_3H_6O_6N_6$	204	222.1	1.816	18.12
Mg	Mg	649	24.31	1.74	0
Liquid Binder	HTPB	(L)	998.3	0.908	-0.888
	HMDI	(L)	168	1.02	-59.08

2.2 SAMPLES PREPARATION

Preparation process begins with mixing of different ingredients using stainless steel mixer of 4 kg capacity where the prepolymer (HTPB), bonding agent (MAPO), burning rate modifier (C), Mg or RDX, if exist, were weighed according to the required formulation and well mixed at 50oC for 15 minutes. Inside stainless steel mixer with a double jacket the temperature was raised up to 60oC through 10 minutes. The dried oxidizer was divided into four equal portions and added to the slurry in series under continuous stirring within 10 minutes at 60oC.Temperature of the slurry was decreased to 40oC and the accurately calculated amount of curing agent (HMDI) was carefully weighted and added. The stirring was continued for 15 minutes at this temperature to insure homogeneity of the paste under vacuum, which was released with nitrogen and stirring was continued for 5 minutes. Casting then curing took place at 65°C for around (3-4) days and daily the hardness shore variation (A) of the propellant samples were measured until no variation observed.

2.3 SAMPLES CHARACTERIZATION

The prepared samples were 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 was measured as the heat released when a material was ignited and burned [14, 15] in a PARR 6200 bomb calorimeter in an inert atmosphere (nitrogen gas). The spontaneous ignition was tested by progressive heating regularly increasing the temperature by 5oC every minute. This test shows the maximum temperature to which the propellant can be subjected during its manufacture and use. The propellant density was measured at 20oC using ordinary Pyckno-meter (density crucible) and silicon oil. The samples of the propellant used to measure the density were being cut in regular and equal shape. The stress-strain relation and modulus of elasticity for the prepared samples were measured by the aid of Zwick (model 1487) testing machine with cross-head speed of 50 mm at 25oC. Burning rate was determined by firing on static benches using 26 mm nozzle which secure an operating pressure of 1.2 as atmospheric pressure. The pressure and time history was recorded for each test and the ballistic performance calculated. Finally signature, primary smoke was measured by trapping the smoke resulting from burning the propellant sample over a ceramic filter having density of 96 g/m^3, thickness of 25 mm and working temperature of 1200^{o}C. The ceramic fibres were weighed accurately before and after the experiment to measure the weight of the captured solid particles in the exhaust smoke was done in a special test rig. Secondary smoke in the gaseous products of combustion was detected by burning 0.5 gram of different propellant compositions in the combustion chamber of gas analyzer device (Gasmet dx4030) used for determination of each product percentage including HCl gas with low levels of detection (0-300 ppm) without need of changing of the rounded electronic sensor.

3 RESULTS AND DISCUSSIONS

Base bleed grain was subjected to very strong mechanical forces acting on the grain resulting from the gases of the gun propellant in the phase of internal ballistics inside the gun barrel and also due to the forces resulting from the wake zone (under pressure zone) in the phase of external ballistics so, the main task of this work is to prepare propellant grains exhibiting a special mechanical properties with low signature effect in-order not to reveal the gun location.

3.1 PREPARATION AND INSPECTION

Base bleed samples were successfully prepared, casted and cured for 72 hours at 65^{o}C, X-ray inspection was done, no surface anomalies were observed, the inner homogeneity was good, no cracks, air bubbles, porosity and foreign matters were found.

3.2 STUDYING THE EFFECT OF BONDING AGENT VARIATION

Three compositions C1, C2 and C3 found in table (3) were prepared to investigate the effect of change of bonding agent on base bleed properties. It is clear from table (4) that the change in bonding agent type and percentage does not make a significant change on density, hardness, heat of explosion, ignition temperature and burning rate. It is obvious from figures (2) and (3) that the three samples offer a good value of stress which remains unchanged even by changing the type of bonging agent from MAPO to mixed MAT4 and also changing the percentage from (0.4%) to (0.6%) mixed MAT4. Also samples show slight increase strain value as we change the type of bonging agent from MAPO to mixed MAT4 with percentage (0.4%) then (0.6%) mixed MAT4 which offers the needed global properties for base bleed grain. This sample is a fruitful beginning except for the strain which remains away from the required strain value (min.30%). hence, another effect should be studied which is the curative ratio (NCO/OH) to increase the strain value and also keeping the other properties in the range of the mechanical and ballistic properties satisfying base bleed applications.

TABLE (3) BASE BLEED FORMULATIONS BASED ON BONDING AGENT VARIATION

Ingredients		Types of bonding agent		
		MAPO C1	Mixed (MAT4) C2	Mixed (MAT4) C3
Binder	HTPB	23.933	23.933	23.742
	HMDI	1.642	1.642	1.633
	MAPO	0.4	0.3	0.45
	Acetic acid	-	0.07	0.105
	Tartaric acid	-	0.03	0.045
opacifire	Carbon black	0.025	0.025	0.025
oxidizer	AP	74	74	74
NCO/OH		0.97	0.97	0.97

3.3 STUDYING THE EFFECT OF CURING RATIO VARIATION

Compositions (C3-C7) found in table (5) were prepared to investigate the effect of curative ratio on base bleed properties. It was obvious from table (6) that the change in curative ratio does not make a significant change on density, heat of explosion, ignition temperature and burning rate and also the samples satisfy the values of base bleed specifications. It was found from figure (4) that as the curative ratio decreases the value of stress decreases and the value of strain significantly increases.

TABLE (4) RESULTS OF BONDING AGENT VARIATION

Properties	Types of bonding agent		
	MAPO C1	Mixed (MAT4) C2	Mixed (MAT4) C3
Density (g/cm^3)	1.507	1.499	1.510
Heat of explosion (cal/g)	804	805	814
Ignition temperature (^{o}C)	309	307	314
Shore A	70	69	68
Burning rate (mm/cm^3)	1.082	1.046	1.052
Density (g/cm^3)	1.507	1.499	1.510

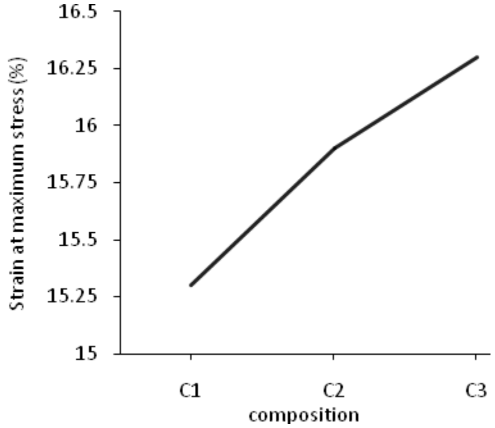

Fig. 2. Stain at maximum stress variation with change of bonding agent type

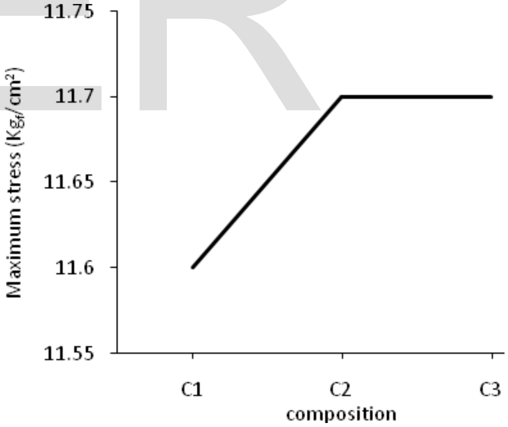

Fig. 3. Maximum stress variation with change of bonding agent type

Together with the young's modulus decrease the hardness also decreases and figure (5) illustrates this phenomena. We had to optimize the properties in order to choose a sample offering the global properties for base bleed grain applications. Sample C5 with curative ratio (0.83) had the optimization balance of properties as its density heat of explosion, ignition temperature and burning rate comply with the required properties for the mechanical properties offering high stress, high hardness and high strain which will be the fruitful beginning of exploring the field of low signature base bleed propellants.

3.4 SIGNATURE STUDY OF CSRP BASE BLEED

The compositions C5, C8 and C9 found in table (7) were prepared to investigate the effect of changing filler type on base bleed properties together with signature.

TABLE (5) BASE BLEED FORMULATIONS BASED ON CURING RATIO VARIATION

Ingredients		Composition				
		C3	C4	C5	C6	C7
Binder	HTPB	23.742	23.853	23.965	24.013	24.175
	HMDI	1.633	1.522	1.410	1.362	1.200
	MAPO	0.45	0.45	0.45	0.45	0.45
	Acetic acid	0.105	0.105	0.105	0.105	0.105
	Tartaric acid	0.045	0.045	0.045	0.045	0.045
opacifire	C	0.025	0.025	0.025	0.025	0.025
oxi-dizer	AP	74	74	74	74	74
NCO/OH		0.97	0.90	0.83	0.80	0.7

TABLE (6) RESULTS OF CURING RATIO VARIATION

properties	Composition				
	C3	C4	C5	C6	C7
Density (g/cm^3)	1.510	1.506	1.510	1.507	1.504
Heat of expl. (cal/g)	814	820	819	821	817
Ignition temp.(^{o}C)	314	313	310	309	307
Burning rate (mm/cm^3)	1.052	1.038	1.028	1.069	1.062

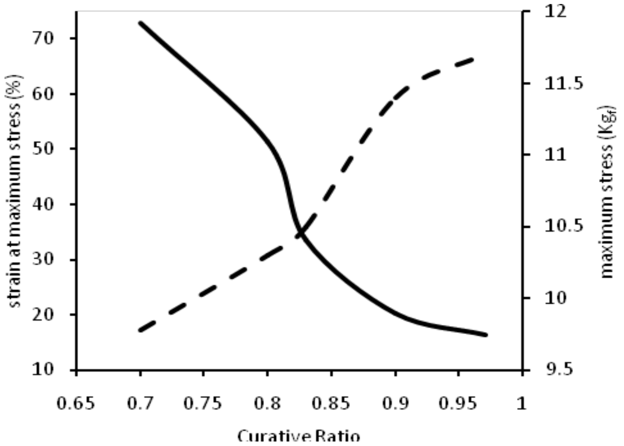

Fig. 4. Stress- Strain Variation vs Change of Bonding Agent Type

It is clear from table (8) that the change in filler type does not make a significant change on density, heat of explosion and ignition temperature as the percentage of RDX in sample C8 and Mg in sample C9 is (5%) instead of AP sample C5, which is too small percentage to make marked change in these properties, also the three samples satisfy the values of BB applications.

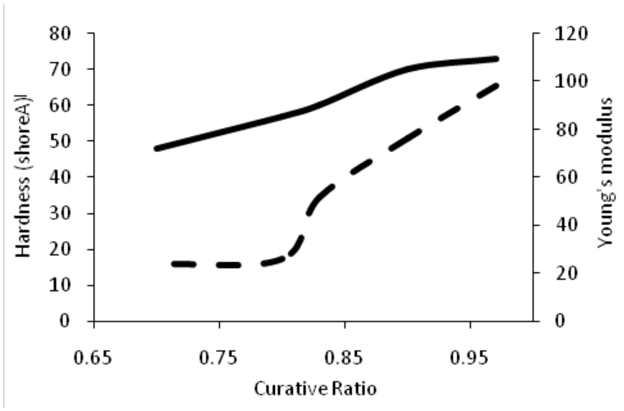

Fig. 5. Hardness-Young's Modulus Variation vs Change of Bonding Agent Type

TABLE (7) BASE BLEED FORMULATIONS BASED ON FILLER TYPE CHANGE

Ingredients		Composition		
		C5	C8	C9
Binder	HTPB	23.965	23.965	23.965
	HMDI	1.410	1.410	1.410
	MAPO	0.45	0.45	0.45
	Acetic acid	0.105	0.105	0.105
	Tartaric acid	0.045	0.045	0.045
Opacifire	Carbon black	0.025	0.025	0.025
Filler	AP	74	67	69
	RDX	0	7	0
	Mg	0	0	5

TABLE (8) RESULTS OF FILLER TYPE CHANGE

Properties	Composition		
	C5	C8	C9
Density (g/cm^3)	1.510	1.506	1.507
Heat of expl. (cal/g)	819	815	816
Ignition temp.(^{o}C)	310	308	306
Burning rate (mm/cm^3)	55	59	60

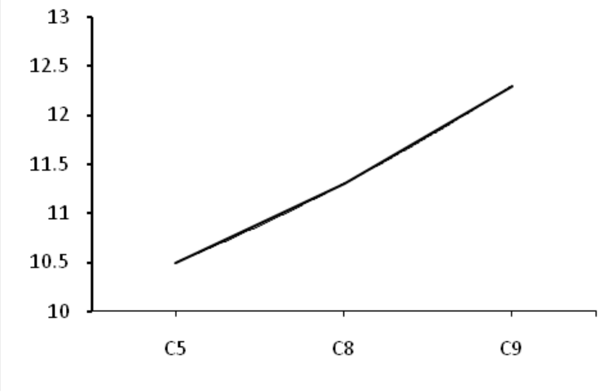

Fig. 6. Maximum stress variation with change of filler type

The addition of RDX in sample C8 decreases the burning rate by (14%) and for Mg addition acts as a fuel in sample C9 the burning rate increases by (25%) where both still found in the required region. The samples satisfy the hardness required with slight increase above the required value of base bleed applications. From figure (6) and figure (7) it was found that the value of stress increases in sample C8 by (7%) and in sample C9 increases by (15%).

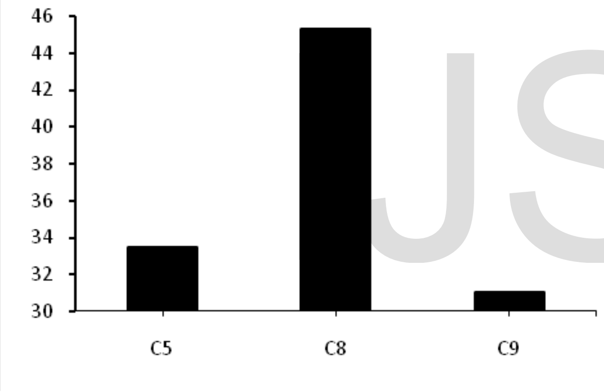

Fig. 7. Stain at maximum stress variation with change of filler type

It was found that sample C8 containing RDX gives (26%) increase in strain and this is reasonable as nitramine based compounds which are able to enhance the bonding behaviour of propellant matrix which in turn affect mechanical properties especially strain at various temperatures. On the contrary do Mg in sample C9, the strain has a slight decrease by about (7%) but still the two samples offer a good value of the strain and satisfy its minimum value required which is illustrated in figure (5), the substitution of AP with RDX sample C8 keeps no primary smoke and decreases the secondary smoke by 34%, while Mg in sample C9 increases the primary smoke to 187 ppm but secondary smoke decreases from 290 ppm in sample C5 to 68 ppm figure (8) and figure (9) clears these phenomena. Changing type and content of the bonding agent (MAPO to mixed MAT4) does not significantly affect the propellant mechanical properties (slight increase in strain).The curing ratio is the main pivot of commands the mechanical properties change.

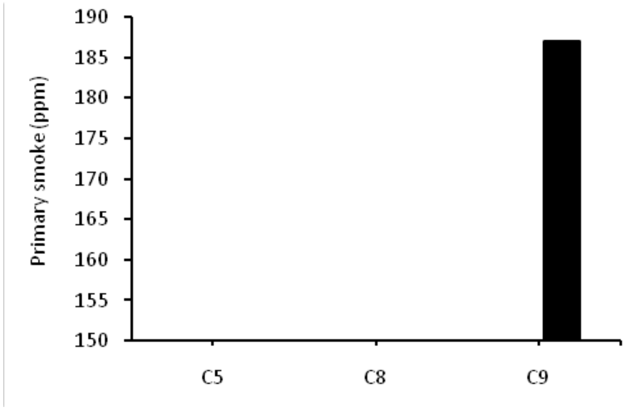

Fig. 8. Primary Smoke Change with Filler Type

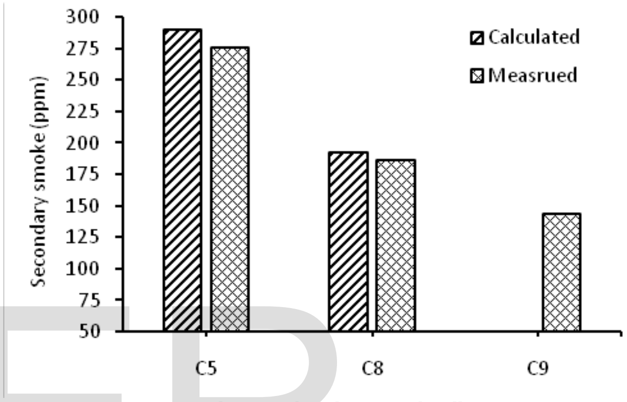

Fig. 9 Secondary Smoke Change with Filler Type

4 CONCLUSION

Sample C8 has good optimization as its density, heat of explosion, ignition temperature and burning rate comply with the required properties also for the mechanical properties offer high stress, high hardness and high strain with low values of young's modulus this is because NCO/OH ratio is <1, so free OH groups are available in the matrix. As RDX is having three nitramine groups, possible H-bonding with the free OH groups increase the overall mechanical property. Also it is free from primary smoke as the conventional formulation but it has an advantage that the secondary smoke is decreased by 34%.

Sample C9 gives no primary smoke and a small amount of secondary smoke when calculated as the neutralization reaction has the ability of completely removing HCl from the exhaust plume, almost certainly if MgO/H2O/HCl aerosol is formed. Ironically it does not give the same results when tested and it is higher than the calculated apparently because of the rapid dispersion of the exhaust cloud when does not give the opportunity for the neutralization reaction to get rid of all the secondary smoke (HCl gas) but still it gives very good results as the secondary smoke is decreased by 75% while the primary smoke is decreased to be 187 ppm

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