Development of a cast plastic bonded explosive with high CL20 content

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Abstract :

SNPE has developed new more powerful cast plastic bonded explosive compositions based on Cl20. These explosive formulations have the particularity to have a filler content up to 91 % in weight.

The composition CL20/HTPB with 91/9 ratio exhibits good performances; the velocity of detonation is 8850 m/s and the calculated detonation pressure is 0.3448 Mbar. Moderate safety properties (friction sensitivity and impact sensitivity tests), shock sensitivity results (Large Scale Gap Test), mechanical properties and vulnerability results have been obtained. Taking into account these performances, this composition can be compared with the pressed explosive LX14.

Until now the compositions containing CL20 led to high levels of viscosity unfavourable with respect to the quality of the manufactured materials.

This composition is obtained thanks to the synergy of several factors which contribute to the quality of the paste. Very low level of viscosities (lower than 5 kP) by batch process are obtained. These viscosities are compatible with the current industrial process procedures for warhead filling. This low viscosity is a main asset to guarantee a good quality of the manufactured samples.

A study of different operational conditions highlighted the effect of the duration and the temperature on the process feasibility. The process reliability was confirmed by characterizing materials after polymerization. The samples manufactured were healthy.

1. INTRODUCTION

Since the 90's, SNPE has developed a new family of cast plastic bonded explosive compositions more powerful and based on CL20. Taking into account their applications, the objective is to obtain a content more than 90 % CL20 in order to increase the performance.

Until now, the explosive compositions including an important content of CL20 conducted to a high level of viscosity which are not favourable to guarantee a good quality of the manufactured materials.

Low levels of viscosity were obtained thanks to works of optimization of the formulation and the process without volatile organic compound.

2. FORMULATION WORK

2.1. Theoretical performances

Performance predictions using numerical computations (CHEETAH 2.0) were performed on a variety of candidate compositions containing HMX, CL20 with inert binder in comparison with the pressed composition LX14.

Table1: CHEETAH calculations

Compositions	ORA 86B	LX 14	CL20-1	CL20-2
HMX	86	95.5		
CL20			91	92
inert binder	14	4.5	9	8
Density (g/cm^3)	1.6863	1.870	1.840	1.861
D cm/µs	0.7800	0.8800	0.8659	0.8790
P_{cj} Mbar	0.2517	0.3532	0.3448	0.3580
Cylinder expansion energy kJ/cm^3 (V/V_0= 7)	0.0695	0.0872	0.0877	0.0901

The numerical computations show that a loading of 92 % CL20 is necessary for obtaining the performance of a composition including 95 % HMX (LX14).

Taking into account these results, optimization works of the formulation and process were carried out to reach a content of 92 %.

2.2. Formulation parameters

The low viscosity of composition with a high content level of CL20 ($\geq$ 91 %) is obtained by the interaction of several main factors:

- choice of ingredients of the binder,
- the influence of the manufacturing process,
- controlled morphology and particle size of CL20.

All these parameters have been tested at one pint scale in a vertical mixer.

Optimisation binders

➢ *Influence of the ingredients:*

The selection of raw material is very important. The mixing of batches with up to 90% CL20 per weight requires an optimal particle size distribution, a nearly spherical solid particles with small specific surface so there is a less need for the binder.

A HTPB system has been chosen to fulfil all requirements for final properties of high performance explosive and its manufacturing process.

The influence of the plasticizer (nature and content) on the end viscosity of mix is very important and the choice of the suitable plasticizer allows to decrease the viscosity and to increase the content of CL20.

The amount of processing aid and the nature of curing agent are also very important.

All the ingredients of the binder system must exhibit a very good physical and chemical compatibility.

Table 2 presents the end of mix viscosity (kP) as a function of different binders:

- The choice of the curing agent MDCI led to a significant reduction of the yield point of the paste at the end of mix for the same viscosity.
- The plasticizers used as lubricant and presenting no solubility contribute to reduce the viscosity.

Table 2: **Influence of binder compounds on the viscosity and on the yield point at the end of mixing for different binder systems**

Composition	1	2	3
CL20	91 %		
Binder HTPB Plasticizer Curing agent	100 DOZ IPDI	100 P0 IPDI	100 P0 MDCI
Temperature	60°C		
Viscosity at the end of mix (kP)*	22	16	15
Yield point (Pa)	NA	2700	800

*Viscosity has been measured with a Brookfield DV-II+, rotation speed 5 rpm.

↳ *Influence of the grade of plasticizers*

Different grades of plasticizers have been evaluated in the end of mix viscosity in the compositions with 91 % CL20. The plasticizers was characterized by their:

- good chemical affinity with HTPB (good miscibility)
- low viscosity
- no solubility of the CL20 in the plasticizers

Table 3 presents the influence of the grade of plasticizers on the end of mix viscosity. Although these plasticizers have very similar in their chemical structures, they lead to very different results of viscosity.

The end of mix viscosity ranges from 4 to 24 kP.

The P1 plasticizer is the most favourable, the measured viscosity was 4 kP before and after curing agent.

Table 3: **Influence of the grade of plasticizers on the viscosity at the end of mixing**

Plasticizers	P0	P1	P3	P5	P6	P7	P8
Viscosity before curing agent (kP)	6.8	4.0	6.0	12.8	22.0	5.6	3 ,7
Viscosity at the end of mix (kP)	8.4	**4.0**	6.0	16.8	24.0	12.0	12.0

Optimisation process

The influence of the mixing duration and of the mixing temperature on the viscosity has been studied.

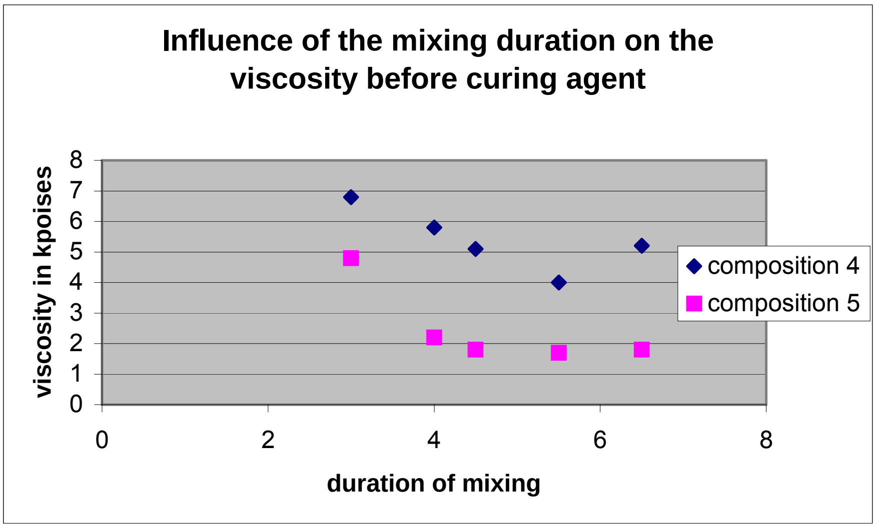
↳ *Influence of mixing duration*

The mixing duration lasted during several hours at 70°C and the viscosity has been controlled at each hour during mixing.

Table 4: Ingredients of the composition

Compositions	4	5
Binder HTPB Plasticizer Curing agent	100 P0 MCDI	100 P1 MCDI
CL20	91 %	

Graph1: Influence duration of mixing on the viscosity



With regard to the duration of mixing, we observe that this parameter improves the viscosity of the paste during the mixing.

This table shows an optimum after 5 hours of mixing and after the paste hardens and viscosity is quickly degraded.

➯ *Influence of the temperature*

Two temperatures have been tested: 60°C and 70°C. Table 5 presents the end of mix viscosity (kP) as a function of temperature. The increase of temperature to 10°C (60 to 70°C) improves the viscosity (gap of 50 %).

Table 5: Influence of temperature on the viscosity at the end of mixing

Composition		6	7
CL20		91 %	
Binder	HTPB Plasticizer Curing agent	100 P0 MDCI	100 P0 MDCI
Temperature		60°C	70°C
Viscosity at the end of mixing (kP)		15	8.4

In conclusion, the temperature and the duration of mixing are two parameters very important to obtain homogeneous and fluid paste.

The robustness of the process was confirmed by characterizing materials after curing. The densities on polymerized materials were correct, they were without porosity.

Influence of the size of CL20:

Grain size, grain distribution, grain shape and grain surface are key parameters to obtain maximal loading.

A new quality of CL20 is being developed to achieve high content of CL20 in cast PBX.

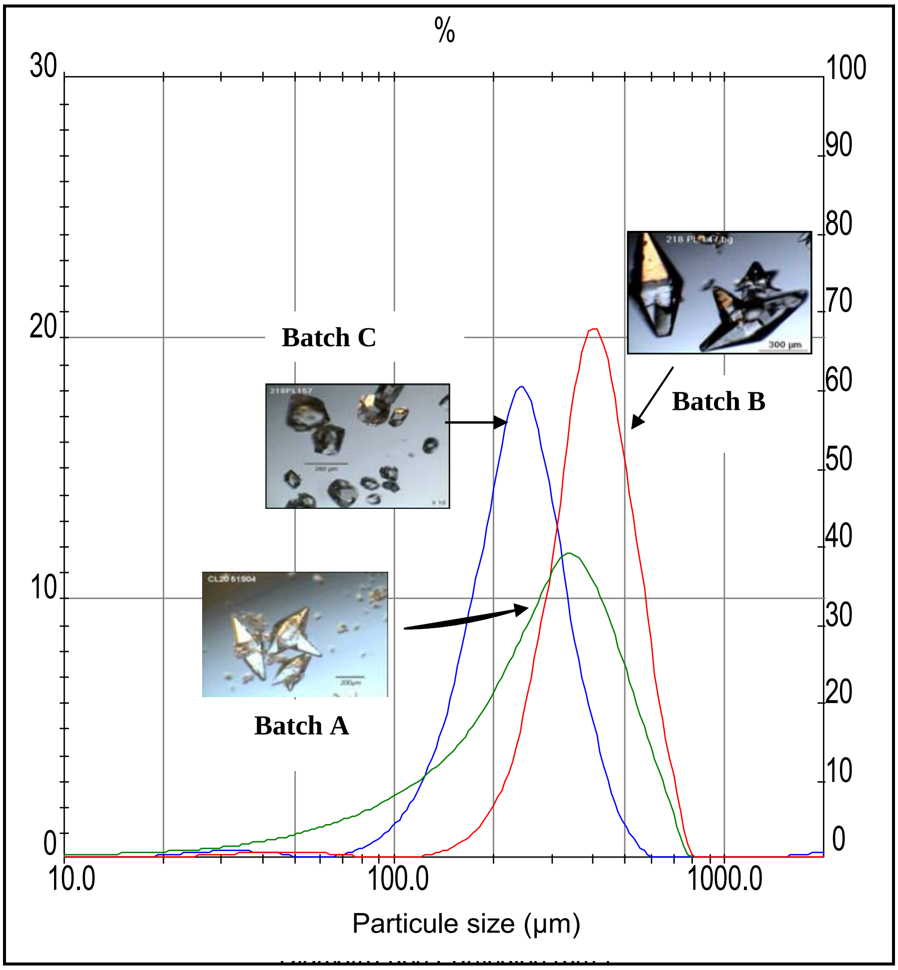
- large particle size d_{50} = 280-400µm
- "compact shape"

Different batches of CL20 with well suited morphology and size were evaluated in the HTPB compositions at two contents of CL20: 91 % and 92 %.

Graph 2 shows the characteristics of the three batches of coarse CL20. Their median sizes are comprised between 280 and 400 µm. Batch A contains a more important fraction of small particles whereas batches B and C are centred in the large diameter. Batches A and B exhibit a bipyramidal shape, batch C presents a rounded structure.

For each batch, two contents of CL20 are tested (91 and 92 %).

<u>Graph 2</u>: Size repartition and morphology for different batches of CL20



<u>Table 6</u>: Viscosity results with different CL20 batches

CL20 batch (reference)		A		B		C	
CL20 composition (%)		91	92	91	92	91	92
Viscosity (kP)	Before curing agent	4	3.2	5.2	7.2	5.6	12.8
	At the end of mixing	4	8	5.2	12	5.2	17.6

At 91 % CL20, the three batches lead to good feasibilities. Viscosity values at the end of mixing range from 4 to 5.2 kP.

At 92 % CL20, we observe more differences; feasibility is degraded since viscosity values range from 8 to 17.6 kP.

The most favourable batch is A, a bipyramidal shape and large particle size distribution. So, the main parameter seems to be the width of the particle size distribution and not the shape of the crystals.

Results are very attractive so one composition has been selected for further evaluations.

3. CHARACTERIZATION

3.1. Mechanical properties at 20°C, crosshead of 50 mm/min

Table 7: Mechanical properties

	Sm (MPa)	E (MPa)	er (%)
91 % CL20	1.25	22	8
92 % CL20	1.6	41	5
ORA86B	1.6	68	3

We obtained correct mechanical properties taking into account the high content of CL20.

3.2. Sensitivity and vulnerability tests

Different tests are performed:

- Impact sensitivity (BAM) according to AOP 7 STANAG 4489 C
- Friction sensitivity (BAM) according to AOP 7 STANAG 4487A
- Temperature of ignition (IT) STANAG 4491

Table 8: Results of sensitivity tests

	CL20 powder	91% CL20 composition	92% CL20 composition*	ORA 86B
Friction sensitivity	≤ 3 J	9 J	12 J	11 J
Impact sensitivity	65-75 N	151 N	12+/30 to 353 N	220 N
Temperature of ignition	225°C	NA	198°C	245°C

* After binder optimisation

These results show that the composition with the high content of CL20 (92 %) presents a good behaviour in sensitivity.

The very good result obtained at impact sensitivity test can be explained by the binder which has been optimized as shower in the previous paragraphs.

➯ **French Large Scale GapTests** (sample size of 40 mm in diameter and 200 mm long confined in a 4 mm thick steel cylinder) were conducted to determine the shock sensitivity.

Table 9: Results of LSGT

	CL20	91% CL20 composition	ORA 86B
Number of cards*	> 360	195	160
P (kbar)	7.2	31.6	44.1

* Acetate cards, 0.19 mm thick

The level sensitivity is acceptable comparatively to the sensitivity of CL20 powder

➯ **Bullet Impact**

At the present time, the bullet impact test has been evaluated for know the pyrotechnical behavior of the army systems with this type of aggression.

The mock-up was SNPE. These characteristics were:

- Thick steel case:............................ 20 mm
- Static burst pressure:..................... 140 MPa
- Volume: .... 1,1 L of explosive composition

The mock-up represents a warhead heavy confined. The 12.7 mm bullet velocity was 870 m/s.

The result after impact was:

Type of reaction: pneumatic deflagration (assimilate to a type IV).

The two lids have been ejected and broke and 21% of product has been recovered.

3.3. Detonation velocity

The velocity has been determined on a non confined cylindrical sample (diameter 30 mm)

Table 10: Results of detonation velocities

Compositions	ORA 86B	91 % CL20	92 %CL20	LX14
Detonation velocity (m/s)	8362	8850	9052	8840

For the 92 % CL20, this experimental detonation velocity is higher than the calculated value by Cheetah 2.0 and the gap is +2.4 % comparatively to the LX14. 1.

4. CONCLUSIONS

New more powerful cast plastic bonded explosive compositions based on CL20 have been developed and partially characterized. The best formulation has a filler content of 92 % in weight.

The formulation and the process of high content CL20 explosive could be compatible with the current industrial process procedure for warhead filling moreover the selected process is without solvent.

The compositions have very good processing characteristics (low end of mix viscosity) and high values in performances (detonation velocity 9052 m/s) at SNPE until now and good safety properties taking into account of their high content of CL20.

ACKNOWLEDGEMENTS

This work was supported by the French Ministry of Defence under contract DGA/DSA/SPNum.