"Paste Explosive Based on Rounded HMX: Rheology, Sensitivity, and Mechanical properties."

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1. Introduction

PBX has been manufactured for several decades by two principle technologies namely, pressing and casting. In the last decade, injection moulding of explosives became also an attractive technology (1,2). The main reason is that this technology enables compositions with higher loadings of solid explosives which can be injected to the final shape without the need for extensive machining. The injection moulded PBX is expected to be more energetic than cast explosives, in addition to having improved mechanical properties and a lower sensitivity under impact loading.

However, the development of such PBX requires extensive knowledge in particle packing and in rheology of particulate systems, because PBX's are actually highly filled particulate composite materials. While pressed PBX is a solid composite material, the injection molded PBX has two phases; first as a particulate paste, having definite rheological properties, and subsequently, after curing, as a solid composite.

Since solid loading is mainly a consequence of particle packing, much effort is spent to obtain a granulation with maximal packing density. It is well known, from various publications (3-5) which deal with packing, that rounded particles are essential for high packing density. Also, it is a common knowledge, that both the maximal solid loading in particulate pastes and the paste viscosity for a given solid loading, depend strongly on the packing density of the filler (6-9).

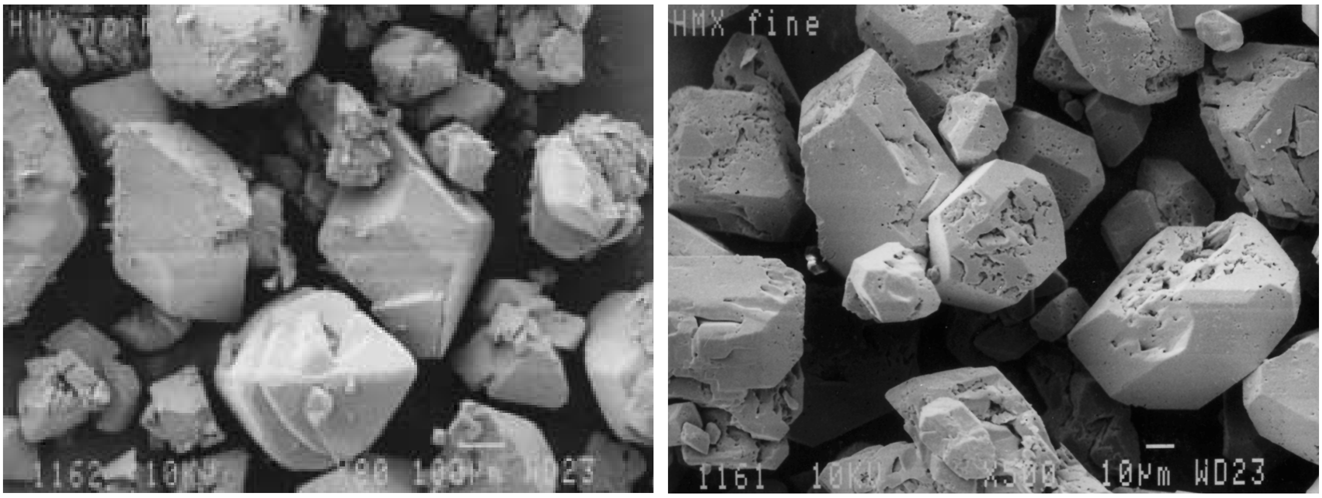
Considering these issues, RAFAEL has developed a special technology for producing rounded particles of different explosive powders (including HMX, RDX and CL-20) to be used in paste explosive technology.

In this paper we describe some work that was done in comparing packing density, solid loading, flow and mechanical properties of rounded versus raw HMX powders. We also describe the end products in terms of the paste explosives made from the said powders.

2. Experimental

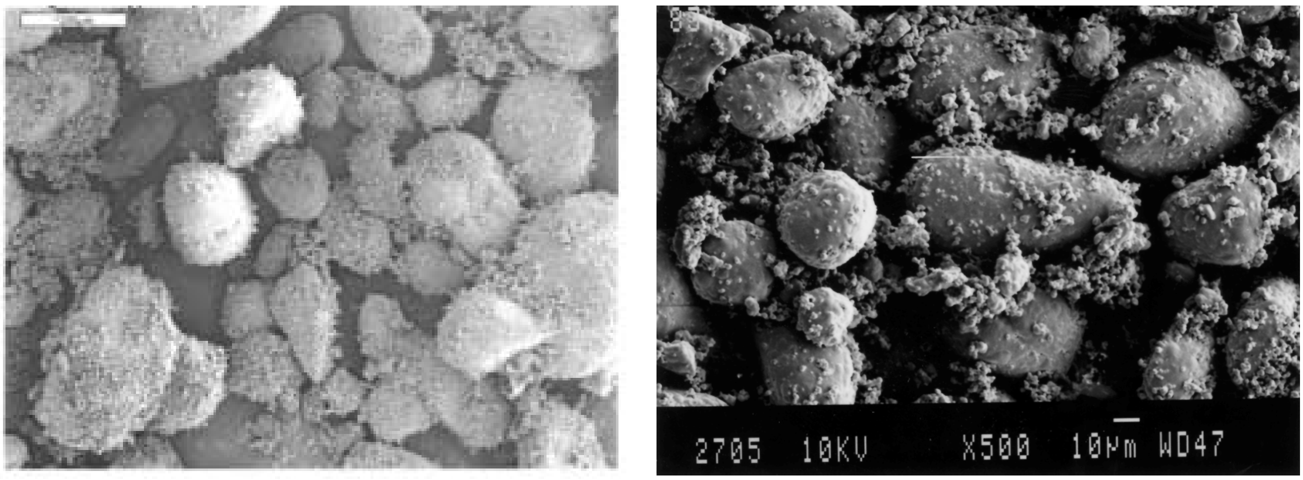
2.1 Raw materials

Explosive powders: Raw shape HMX in two fractions of ~50mm and ~150mm, and rounded HMX in two fractions, produced by the RAFAEL special technology - SEPT. Fig. 1 presents SEM micrographs of the fine (50mm) and coarse (150mm) HMX which serve as the raw material. These materials were subjected to the rounding process (SEPT), after which the particles look as in Fig. 2.



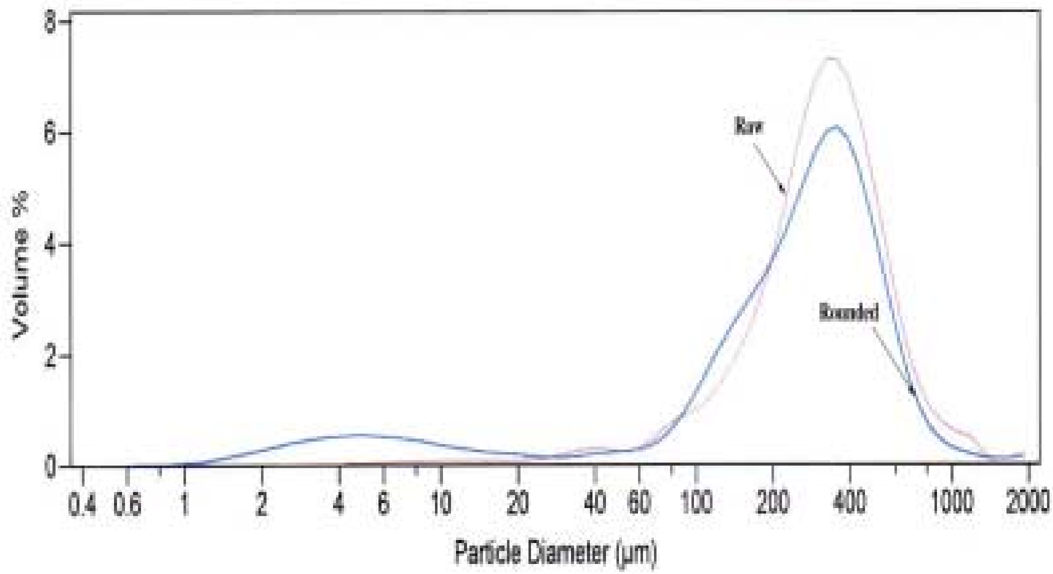
a. Coarse HMX (x80) *b. Fine HMX (x500)*

Figure 1: Raw Material (Note the Different Magnification in the two Pictures)

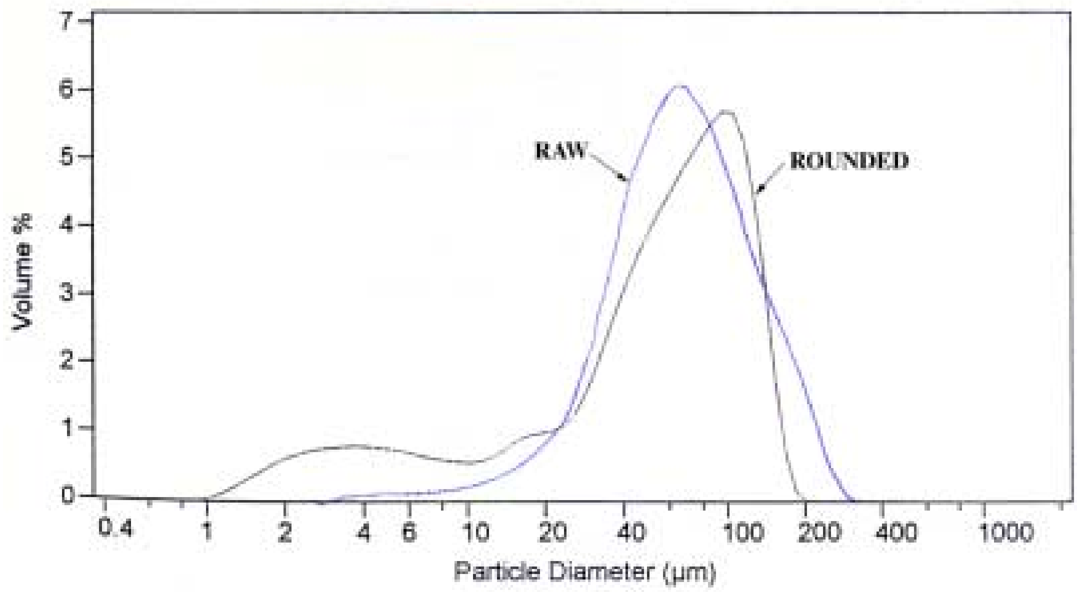


a. Rounded Coarse HMX (x100) *b. Rounded Fine HMX (x500)*

Figure 2: The Rounded HMX Particles (Note the Different Magnifications)



a. Coarse Raw and Rounded HMX.



b. Fine Raw and Rounded HMX.

Figure 3: Particle size Distributions

Particle size distribution of these powders was analyzed by a Coulter LS-230 and the results are shown in Fig. 3. As is clearly seen, the basic characteristics of these distributions did not change much with rounding

The binder is a Siliconic resin - PG-121, manufactured by Polymer Gevulot, Israel. The resin is combined with a suitable plasticizer.

2.2 Packing density

The packing density of different powders was defined by wet tap density measurements. The method is based on immersing the tested powder in water and tapping the wet mixture in a transparent cylinder for 10 minutes. The excess water is squeezed out of the packed powder by applying mild pressure of $8kg/cm^2$ for 5minutes which results in some extra densification. The packing density is calculated from measured net weight of the powder, and it's volume in the cylinder. It is depicted in values of %TMD. The measurement precision is: ±0.05mm for height and diameter and ±0.01gr for weight.

2.3 Compounding and specimen preparation

The formulation is compounded by a 5 liter sigma blade high shear mixer manufactured by Aoustin (France). After mixing, the explosive paste is deaerated by a device which was developed especially for this purpose. Subsequently, the paste is injected through a rectangular slit and pressed to a plate shape. The plates are cured in an oven at 60°C for 12 hours, and then cut to dog-bone specimens.

2.4 Flow properties

Flow properties of the compositions were determined by measuring the flow rate trough a ϕ3mm x 20mm nozzle under pressure of $30kg/cm^2$. Flow rate was measured for compositions with 74vol% solid loading and different particle size distributions, and particle shape .

A flow rate of 5 - 10 gr/min was the criteria for maximal solid loading.

2.5 Mechanical properties

Dog bone specimen 6 mm thick, were tested under tension by an Instron machine at lever rate of 0.05cm/min at 25°C. These tests show the stress-strain curve, maximum strength and strain for failure.

3. Results and discussion

3.1 Packing density and solid loading

Packing density data for the different HMX powders which were tested in the current work, is shown in table 1 along with the maximum solid loading in the paste. It is evident that the rounded particles pack to larger density as compared with the raw powders. The density increases by 5-12 %TMD, as a consequence of using rounded particles. This result in agreement with the literature (3-5).

Table 1- Packing Density and Max. Solid Loading of HMX Powders.

HMX Type	Packing Density (%TMD)	Max. Vol% in Paste	Main Features of the Powder are shown in
raw fine	61	62	Fig. 2a 3b
rounded fine	73	74	Fig. 2b 3b
raw course	71	72	Fig. 1a 3a
rounded course	76	83	Fig. 1b 3a
raw bimodal	72	70	Fig. 4
rounded bimodal	81	83	Fig. 5

Fig 6 shows the maximal solid loading in the paste as a function of the tap packing density. The linear relationship shown in the figure is quite expected, according to the models of forecasted solid loadings in pastes based on data of packing density.

Moreover, the maximum solid loading is similar or larger than the %TMD defined by the packing density measurements. This result is quite surprising, since the packing density measurements are conducted with water and a surfactant for improved wetting, while the pastes are prepared with a siliconic resin with a much larger viscosity. A possible explanation for this result is that due to agglomerated micronized particle population, which exists mainly in the rounded powders. These agglomerates cannot be disassembled by the manual mixing in the first stage of tap density measurements, but they may be disassembled by the high shear of the sigma blades.

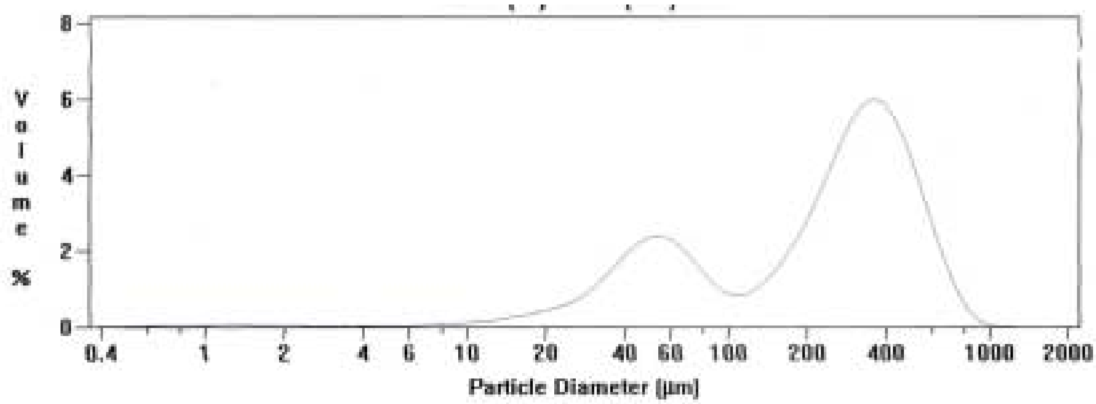


Fig. 4 – Particle Size Distribution of Coarse (70%) and Fine (30%) Raw Mix.

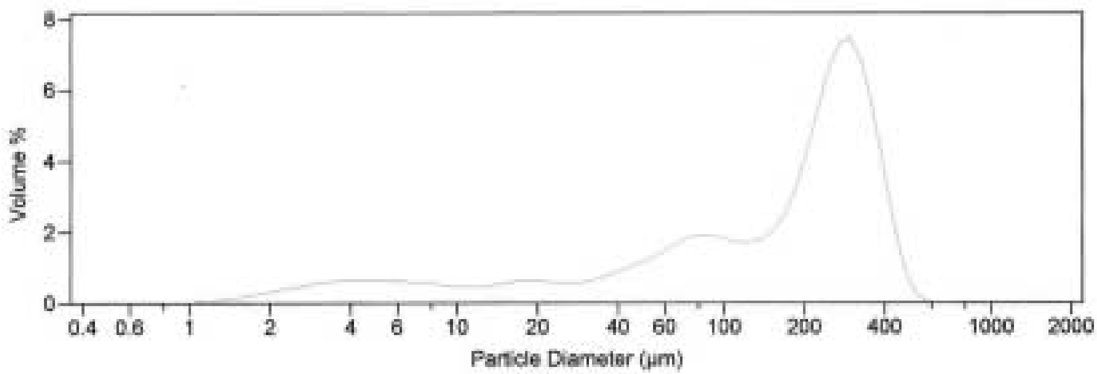


Fig. 5 – Particle Size Distribution of Coarse (70%) and Fine (30%) Rounded HMX

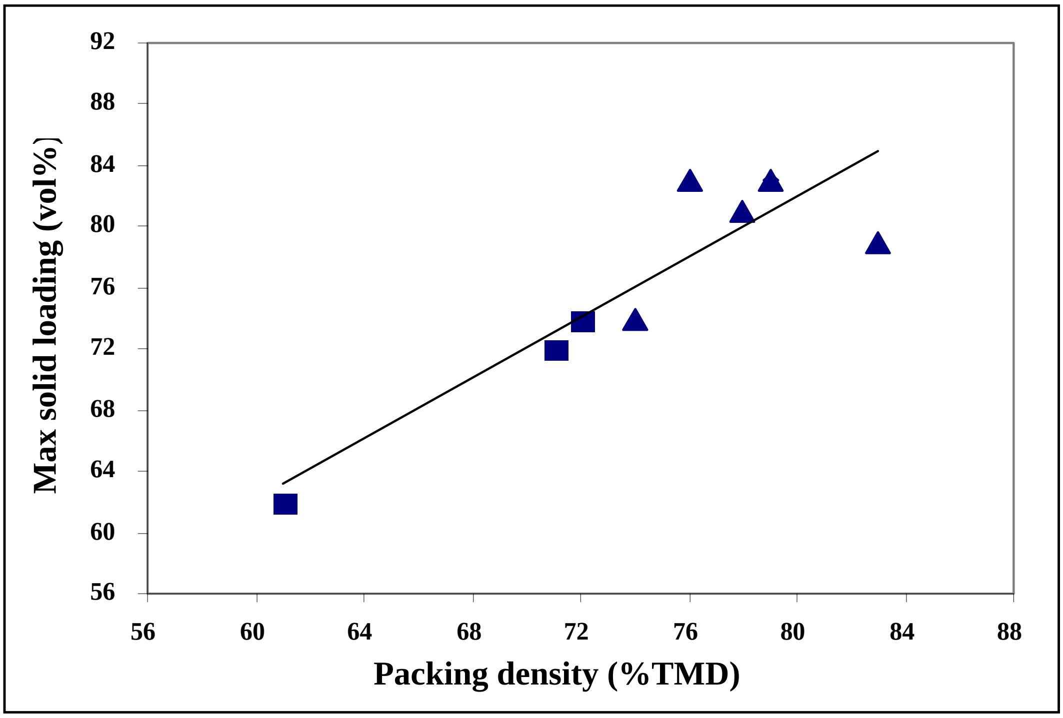


Fig. 6 - Maximal Solid Loading as a Function of Tap Density for Different Granulations.

▲ - Rounded Powder ■ - Raw Powder

3.2 Flow properties

Flow rates of paste batches, with different granulations, were measured for a fixed solid loading (74vol%) as described in section 2.4. The flow rate results are given in Table 2.

<u>Table 2</u> – Flow Rate of Paste Compositions

Batch No.	Powder Features	Vol% HMX	Flow Rate (gr/min)
H-1	raw bi-modal HMX 70% coarse + 30% fine	74	18
H-2	rounded pseudo bi-modal HMX 70% coarse + 30% fine	74	529
H-3	rounded coarse HMX	74	315

A mixture of coarse(70%) and fine(30%) raw HMX particles, results in a classic bi-modal distribution (fig. 4). In contrast, a mixture of rounded course and fine HMX in the same proportions, makes a pseudo bi-modal or tri-modal distribution (fig. 5). This difference by itself can have an influence on the flow properties of the paste. However, rounded coarse HMX is also a bi-modal powder (fig. 3a), resulting in a high solid loading and good flow properties, which are close to those of the rounded HMX mixture. According to these results, it is evident that the rounded shape of the particles is the main reason for the much-improved flow properties of H-2 and H-3. This result is in agreement , with the literature (6,7,9), still, it is very interesting to note the large differences in the resulting flow rates. Between the two batches with the rounded particles, the difference in flow rate is relatively small, since regarding flow properties, only differences of about one order of magnitude are considered significant.

3.3 Mechanical properties

Mechanical properties under tension were obtained for specimen made of paste batch prepared from fine raw HMX particles, and paste batch made of rounded fine HMX (fig. 2b, fig.3b). For the sake of comparison, the paste batches contain only 62vol% HMX, which is the maximal solid loading for the paste made of fine raw HMX. The particle size distribution is quite similar in both powders, so we could examine the influence of particle shape on the mechanical properties of cured paste explosive. The results as given in Table 3, show that by using rounded particles, a factor of almost 2 is obtained for the strain to failure, with an appreciate increase in strength. This result is not obvious, and its explanation is not straightforward. Reference (10), claims that in a similar comparative study of mechanical properties, where the main difference is the binder which was HTPB and not a siliconic resin, there was no any influence of particle shape on mechanical properties. This apparent discrepancy can be explained, by considering the failure mechanism of highly filled composite materials. Failure of such materials starts at defects inside the bulk. Sharp edges, irregular shapes, porosity or corners of particles, induce stress concentration which enhances failure (11). Obviously, rounded and smooth particles create less defects and, as a result, inhibit failure.

Still there is an important gap of knowledge concerning the strength of adhesion between the filler particles and the binder material. As stated in (11), the level of adhesion affects the dominance of particle features on the mechanical properties of the composite material. In composites with low adhesion, the influence of particles will be very pronounced. For composites with good adhesion, particle features have less influence on mechanical properties.

Table 3 - Mechanical Properties of Paste Explosive with Different HMX Shapes.

Batch No.	HMX Type	Strength (kg/cm^2)	Strain to Failure (%)
HR-1	raw fine	2.8	2.7
HR-2	rounded fine	3.7	4.5

4. Conclusions

The following are the main conclusions of our study:

1. Packing density is increased significantly by using rounded HMX particles.
2. Maximal solid loading in pastes made of rounded particles is higher by ~ 10vol%.
3. The flow rate of paste explosives increases by an order of magnitude as a result of using rounded particles.
4. Mechanical properties can be significantly enhanced by using rounded particles. The magnitude of this increase seems to be related to degree the of adhesion between the particles and the binder.

Acknowledgements

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5. References

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