PROCESS DEVELOPMENT AND PRODUCTION SCALE UP OF NEW EXPLOSIVE COMPOSITIONS AT HOLSTON ARMY AMMUNITION PLANT

by

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ABSTRACT

Holston Army Ammunition Plant is a major producer of explosives for the U.S. military. The U.S. Army and Navy have developed new RDX / HMX compositions (PAX-2A and PBXW-17 respectively) to meet the performance, cost, and Insensitive Munitions requirements of future military programs. In addition, to military explosives, Royal Ordnance North America, Inc. (RONA), the operating contractor of HSAAP is also expanding its RDX / HMX product range for commercial applications. New compositions such as HMX / WAX are being developed by RONA for commercial shaped-charge applications.

This paper describes the process development and product characterization work underway at HSAAP in support of RONA's product range enhancements. All of the products being developed utilize existing core manufacturing capabilities at HSAAP, namely solvent lacquering of explosives. Not all of the explosive compositions mentioned lend themselves to solvent based processing using standard techniques. RONA has had to employ some novel manufacturing approaches as part of the formulation development activities. Details of the manufacturing techniques utilized, material and processing issues, product properties and performance, and projected product costs are discussed.

1. INTRODUCTION

1.1. Holston Army Ammunition Plant (HSAAP) is the only U.S. based manufacturer of RDX / HMX based explosives has historically been the primary supplier of explosive compositions for U.S. military applications.

1.2. Core competencies of HSAAP include the bulk-scale manufacture of RDX and HMX and formulation of both plastic bonded explosive (PBX) and melt-cast explosive compositions. In all, more than 75 explosive intermediates and compositions have been manufactured at HSAAP in the past to support a variety of military applications such as bomb fills, demolition products, warhead boosters, etc.

1.3. In the past, the contractor technical staff at HSAAP has worked closely with both Army and Navy research laboratories to develop and scale up new, improved explosive formulations. Many examples can be provided of explosives, which were mutually developed with the military research laboratories and scaled to production quantities at HSAAP including LX-14-0, CXM-7, CXM-9, PBXN-5, PBXN-7, PBXN-9, and PBXW-11.

1.4. In January 1999, Royal Ordnance North America, Inc (RONA) became the new operating contractor of Holston AAP. During the transition of operating contractors at HSAAP, RONA placed substantial emphasis on retaining the critical skills required to develop, scale up and manufacture explosive compositions.

1.5. RONA is committed to enhancing the current HSAAP product range in order to maintain the viability and competitiveness of HSAAP. In recent months, product development work has been conducted by RONA to expand the current product range of explosives manufactured at HSAAP. These development efforts have focused on Army, Navy, and commercial products.

1.6. Such development programs are considered especially important following the completion of a major facilities modernization investment undertaken at HSAAP by RONA using BAE SYSTEMS funding ($15m over FY 1999 and 2000), details of which are reported elsewhere[1].

1.7. As part of the commitment to maintain and improve the HSAAP product range, RONA has invested IR&D funding during CY 2000 into the process development of a number of new (for HSAAP) explosive compositions.

1.8. This paper provides a situation report on the explosive process development efforts undertaken during CY 2000 on the following explosives:

1.8.1. PAX-2A – a high performance IM explosive developed by the U.S. Army ARDEC;

1.8.2. PBXW-17 – a low-cost alternative to the IM explosive PBXN-9;

1.8.3. HMX / WAX – a very high performance HMX based commercial explosive.

1.9. None of the product and process development programs are as yet complete; this paper thus represents a snapshot of where the development programs are now (November 2000).

2. PROCESSING METHODS AND EQUIPMENT

2.1. HSAAAP has considerable historical experience with the production of explosives using a solvent-lacquering process. This essentially involves dissolving the coating medium (a polymer, wax, plasticizer, grease, oil etc.) into an organic solvent then mixing with a water-wet slurry containing the target nitramine. The solvent is distilled off, recovered and re-used leaving the nitramine coated with the coating medium.

2.2. The advantage of this method is that it produces a very high quality "polished" product. The particle size distribution of the material can be modified (by adjusting the processing conditions) to suit the final requirements. HSAAP is equipped to manufacture products using this technology on an industrial scale (6,000-gallon recrystallization and product formulation stills), which results in a low-cost product relative to other production methods.

2.3. Additionally, HSAAP is also equipped with small-scale versions of the production equipment (0.5 – 3 gallon laboratory stills and 500-gallon "pilot scale" stills). This equipment is designed to facilitate a seamless transitional scale-up from basic process research (0.5-gallon) through to full-scale production (6,000 gallons). All three process scales are considered critical and are typically utilized in the development of a robust manufacturing process for a new explosive composition.

2.4. HSAAP has historically used this equipment to conduct all process development scale-up activities. This scale-up process has proved to be reliable and consistent when used by Holston Defense Corporation (the previous HSAAP Operating Contractor) in the past, and has thus been adopted by RONA as a low-risk technical approach for the product-development efforts described herein.

2.5. RONA employed the solvent-lacquering approach in the development of the processing methods for the manufacture of PAX-2A, PBXW-17 and HMX/WAX. These products have been processed at varying scales of operation: up to 1 gallon scale for PBXW-17, up to 3-gallon scale for PAX-2A and 1, 3 and 500-gallon scale for HMX / WAX.

3. PROCESS DEVELOPMENT STATUS

3.1. PAX-2A

3.1.1. PAX-2A is a high performance pressable explosive designed to have superior "Insensitive Munitions" properties compared with conventional explosives. The U.S. Army (ARDEC) developed the explosive; its properties are widely reported in the open explosive literature. The composition of PAX-2A consists essentially of the following within:

3.1.1.1. HMX Class 5 - 85% $^{w}/_{w}$

3.1.1.2. Cellulose Acetate Butyrate (CAB; polymer) - 6% $^{w}/_{w}$

3.1.1.3. BDNPA/F (energetic plasticizer) - 9% $^{w}/_{w}$

3.1.2. Details of the PAX-2A formulation are given in military specification MIL-P-71053 (AR), 22 June 1994.

3.1.3. PAX-2A is designed for use in a number of applications, including shaped charge and fragmentation / metal acceleration. The explosive is designed to be pressed into final shape.

3.1.4. PAX-2A has a number of specification criteria. Some of the critical features of PAX-2A include the ability of the material to flow and the bulk-density (both of which are highly important for high-speed pressing facilities). RONA has evaluated these criteria for the products manufactured at HSAAP. Additionally, RONA has determined a means of influencing these important product characteristics by carefully controlling the manufacturing process and by judicious solvent selection.

3.1.5. PAX-2A has been manufactured on the small scale at HSAAP by RONA (up to 3-gallon scale). The following table summarizes the range of flow characteristics and bulk-density of the product, as produced by the different manufacturing conditions employed:

TABLE 1 – EXAMPLE PAX-2A CHARACTERIZATION DATA

Characteristic	Batch 796-68	Batch 796-70	Batch 796-71	Batch 796-75	Batch 796-76
Coefficient of friction (g/cm-sec^2)	98	68	295	262	80
Bulk density (g/cc)	0.80	0.64	0.86	0.89	0.65
Coefficient of friction data obtained using a FLODEX instrument. Bulk density results obtained using the U.S. Army Drop Cylinder technique detailed in MIL-STD-650.					

3.1.6. These data in Table 1 show that RONA has successfully developed a process for manufacturing different types of PAX-2A in terms of bulk density, mean size and flow characteristics. To date, RONA has been unable to manufacture PAX-2A at the highly desirable 1.0 g/cc bulk-density value, although efforts thus far have been encouraging and indicate that this target is potentially achievable using the employed technology.

3.1.7. Some of the PAX-2A results reported (e.g. batch 796-68) relate to material, which has a uniform particle size. This lends itself well to auto loading as sedimentation cannot occur. Some other batches, e.g. 796-75, have improved bulk densities, but the granules are not all of the same size, thus sedimentation would be expected in vibrated auto loaders.

3.1.8. Clearly, RONA still has some work to do to further develop the PAX-2A manufacturing process. However, given where we were just 8 months ago, RONA is encouraged by the achievements to date and has every intention of continuing with these efforts.

3.1.9. RONA's development efforts will continue to utilize the solvent lacquering technique because this will provide what RONA believes will be the most cost effective manufacturing solution for PAX-2A users (also see section 4 – PRODUCT COST ESTIMATES).

3.2. **PBXW-17**

3.2.1. PBXW-17 is an RDX-based pressable explosive developed by NSWC. The explosive nominally consists of the following ingredients:

3.2.1.1. RDX Type II (classes 1 & 5, nominal 50/50 ratio) - 94% $^{w}/_{w}$

3.2.1.2. Polyacrylic elastomer (Hytemp 4544) - 1.5% $^{w}/_{w}$

3.2.1.3. Di-(2-ethylhexyl) adipate (DOA) – 4.5% $^{w}/_{w}$

3.2.2. Full details of the PBXW-17 formulation are obtainable from Naval Systems Sea Command (SEA-05M).

3.2.3. PBXW-17 is designed as a low-cost replacement for PBXN-9. Both explosives are intended for use in metal acceleration and/or fragmentation applications. PBXW-17 is the RDX analogue of PBXN-9, which contains HMX (and is thus more expensive).

3.2.4. PBXW-17 has requirements for bulk-density and flow characteristics. RONA has manufactured several variants of PBXW-17 under different conditions, although at this time, formulation development has been limited to the 1-gallon still only.

3.2.5. Results for some of the batches of material produced are as follows:

TABLE 2 - EXAMPLE PBXW-17 CHARACTERIZATION DATA

Characteristics	**Specification**	**Batch 796-63**	**Batch 796-82**	**Batch 796-84**
Bulk Density (g/cc)	0.79 min	0.82	0.87	0.88
Coefficient of friction ($g/cm\text{-}sec^2$)	-	121	149	108
Dry Sieve Results (% passing):				
USS 6	99-100	100	100	100
USS 8	95-100	100	99.9	100
USS 40	0-5	0.5	2.0	0.0
USS 70	0-1	0	0	0

3.2.6. As can be seen from the above Table, RONA has manufactured different types of PBXW-17, all of which meet the specification requirements, yet exhibit different physical properties in terms of flow. Generally, a low coefficient of friction is desired for pressable explosives.

Although the coefficient of friction parameter is currently not specified in the PBXW-17 material specification, batch 796-84 is the most likely favored candidate, all other factors being equal. RONA intends to use the manufacturing process for batch 796-84 as a basis for future scale up efforts for PBXW-17.

3.2.7. One potential manufacturing issue for PBXW-17 is the firmness of the product. There is no specification requirement for the firmness of the granules, but RONA has observed that the PBXW-17 reported above is relatively soft compared with PBXN-9. This may improve the pressability of the composition but might also give rise to storage problems (compaction). This potential issue will need to be investigated further.

3.3. **HMX / WAX**

3.4. HMX / WAX is a generic name used by RONA to describe a product family used typically by the oil and gas service industries. The HMX / WAX is pressed into small, highly efficient shaped-charges which are used to perforate substrate to enable oil and/or gas to be recovered from underground reservoirs.

3.5. In the past, such commercial users were not served from HSAAP owing to the previous HSAAP Operating Contractor's reluctance to service commercial markets. In contrast, as the new Operating Contractor for HSAAP, RONA is aggressively pursuing both military and commercial markets. For this reason, RONA is developing a range of products that can be used to supply a number of commercial markets, including the oil and gas service industry.

3.6. Precise details of the formulation(s) employed in the industry are often customer specific and proprietary. However, in general, they typically employ HMX (various classes) coated with desensitizing agents, which include waxes and other materials. RONA uses the generic name "HMX / WAX" to classify all of these products for the purposes of this paper.

3.7. To date, HMX / WAX has been manufactured by RONA on the small (1-3 gallon) and medium (500-gallon pilot; 500 LB batch size approximately) scale equipment. A number of different formulations have been manufactured, generic details of which are given below. The first table below shows the results for small-scale (1-3 gallon) efforts. The second table shows results for the pilot scale (500-gallon) efforts:

HMX / WAX SMALL SCALE (0-3 GALLON) EXPERIMENTAL RESULTS

PARAMETER	BATCH NUMBER							
	RX-1	**RX-2**	**RX-3**	**RX-4**	**RX-5**	**RX-6**	**RX-7**	**RX-8**
Bulk density (g/cc)	0.94	0.91	0.98	0.96	0.98	0.97	0.98	1.02
Flow (seconds)	22.2	22.3	20.1	22.6	22.9	22.7	22.1	21.1
Flow measured using Hall-Carney apparatus, with a 25g sample of ungraphited material.								

HMX / WAX PILOT SCALE (500-GALLON) PRODUCTION RESULTS

	BATCH NUMBER			
PARAMETER	**296-22**	**296-23**	**296-24**	**296-25**
Bulk density (g/cc)	1.02	1.01	1.09	0.95
Flow (seconds)	19.3	19.3	19.3	20.8
TGA (% mass loss)	1.35	1.32	2.09	1.42
Decomposition Temperature (°C)	287	289	>287	286
Decomposition temperature measured by DSC. Flow measured using Hall-Carney apparatus, with a 25g sample of graphited material.				

3.8. The product data summarized above relates to several different HMX / WAX compositions, which are physically similar in terms of bulk density etc., but are chemically quite different. Specification data are not included owing to their proprietary nature.

3.9. The different HMX / WAX products manufactured on the pilot scale (500-gallon, nominally 500 LB batch size) have been evaluated and effectively utilized by Customers. RONA is now actively pursuing the third and final scale up effort required to produce this material in full scale production quantities, with initial target batch size of 3,000 LB, but an ultimate objective to utilize the full capacity of the 6,000 gallon HSAAP product formulation stills.

4. PRODUCT COST ESTIMATES

4.1. As ever, the final cost of a product is always a key element and is often of greatest importance to potential customers.

4.2. For this reason, RONA has focused exclusively on solvent-lacquering technology to produce the explosives described above. Products can be manufactured using this technique at a large, cost-effective scale at HSAAP. RONA believes that employing our core-competency and truly industrial-scale-manufacturing facility in this way will result in the lowest cost for these materials in the industry.

4.3. Our current projected cost to the customer for these products is as follows:

PRODUCT	ESTIMATED PRICE ($ / lb)
PAX-2A	< 30
PBXW-17	< 8
HMX / WAX	< 22

4.4. Clearly, actual product cost depends upon volume, final destination, export / import fees, transport etc. The figures provided above incorporate the basic assumption that the materials can be successfully manufactured using HSAAP core technology; viewed by RONA as being low risk. The figures given above are intended to be a guide. Further details can be obtained by contacting RONA.

5. FUTURE WORK

5.1. RONA fully intends to continue developing the manufacturing processes required to enable a full production capability for PAX-2A, PBXW-17 and the HMX / WAX series of products. The PAX-2A and PBXW-17 development efforts are still being conducted on the small scale (1-3 gallons). This situation reflects both the levels of IR&D that can be expended to support these programs and the processing complexity issues identified (and being addressed) during the development efforts.

5.2. For the HMX / WAX series of compositions, the development efforts have resulted in a partial scale up to the 500-gallon vessels (nominal 500 LB batch size). Whilst this is not RONA's most efficient manufacturing method, the revenues generated by the sale of these materials are supporting the third and final scale-up to full production efforts (>3000 LB batch size). This is now being actively progressed by RONA.

5.3. The efforts described herein reflect RONA's first full year of undertaking product development activities. RONA is committed to supporting these development efforts in order to meet the needs of military and commercial customers; to provide a high quality product at the most competitive price.

5.4. The work described herein also represents one element of the product and technology thrusts being pursued by RONA. These R&D activities are being implemented to support RONA's vision of becoming a center of excellence in the field of secondary explosive supply, service and support.

5.5. In addition to the PAX-2A, PBXW-17 and HMX / WAX series of compositions, RONA fully intends to pursue other product development opportunities.

6. REFERENCES

1 A.R.Wilson and M.J.Ervin, "Update On The Modernization Of The Holston Army Ammunition Plant", presented at the NDIA Insensitive Munitions and Energetic Materials Symposium, Tampa, FL, December 1999.

7. ACKNOWLEDGEMENTS

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