

Twin Screw Extrusion of
Aluminized Thermobaric Explosives

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Abstract

The manufacturing of advanced explosives containing large amounts of metallic powders needed for enhanced performance characteristics, such as PAX-3, has proven difficult to transition into large scale production. Current manufacturing processes have produced low yields, which results in a high cost per unit and questionable product uniformity. Over the past year the Twin Screw Extruder (TSE) Team has been investigating the use of a TSE machine to mix and extrude an aluminum based explosive, (PAX-3). The TSE team has successfully demonstrated this concept. This material was processed using a lower concentration of solvents, in comparison to conventional batch processing, and is more uniform in appearance.

The TSE method uses a base material consisting of coated HMX (PAX-2 or PAX-2A), made by a conventional slurry mix, and reprocessing it into its aluminized corollary. This manufacturing process is extremely flexible allowing for the reformulation of a base material into a number of different explosives with tailored characteristics.

By using this new technology, the cost of manufacturing these explosives would be reduced by \$10 to \$60 per pound depending upon how successful current batch process improvements are. The organic solvents lost to the environment and waste treatment requirements will also be greatly reduced. It is anticipated that the concentration of the organic solvents will be reduced by as much as 50% compared to traditional batch processes. It will also be economically practical to recover and reprocess scrap and out-of-specification explosives.

Introduction

Due to the changing needs of the war-fighter today, new tailor-made insensitive explosives are needed to defeat specific threats. These new explosives require both armor defeat and enhanced blast capabilities. One type of new explosive capable of these effects is Picatinny Arsenal Explosive - 3 (PAX-3). PAX-3 developed in the early 1990's is an aluminized corollary of a desensitized HMX explosive (PAX-2 or PAX-2A). Due to reactions between H₂O and the metallic particles, it has been found to be difficult to manufacture these types of materials through conventional slurry mix methods, used to manufacture PAX-2A. Other major factors that contribute to the difficulty in transitioning to large scale production is the inability to control process variables and process parameters, i.e. temperature profile, shear rate, goodness of mix and particle dispersion. This inability has produced an increase in waste, thus driving up production costs.

In the late 1990's the Twin Screw Extruder (TSE) team at Picatinny Arsenal, NJ successfully produced PAX-2A through a twin screw extruder. Subsequently, this was determined not to be as cost effective as slurry mixing process. With the inherent difficulties and increased costs associated with producing PAX-3 by conventional means, it was proposed that PAX-3 be processed through a twin screw extruder in order to lower costs and ensure a high quality product.

Theory

In order to process PAX-3 through a twin screw extruder, one must first understand processing at the particle scale. The key control variables are: HMX particle size, HMX particle size distribution, Al particle size, Al particle size distribution, order of addition, and rate of addition. HMX and Al particle size and particle size distribution are defined in formulation specifications for PAX-3. These constraints reduce the number of process control variables from six to two; order of addition and rate of addition.

It has been found that these two variables are very important to produce a high quality mix. Order of addition is an essential consideration and should not be overlooked. Through the initial study on the development of PAX-2A, in the late 1990's, it was found that by adding solvent too soon the mix would form a gel that could not be processed. This gel led to areas of HMX rich material (uncoated particles) and coating-material rich areas. This decreased the effectiveness and insensitivity of the material being produced. The problem was solved and in the late 1990's the TSE team produced a high quality PAX-2A through a twin screw extruder.

When examining why it was difficult for batch mixes to produce a high quality consistent product in large amounts, it was found that the Al particles were added too soon and encountered poor mixing. This poor mixing led to the coating of Al particles in preference to the HMX crystals. Poor dispersion led to areas of

uncoated HMX crystals and areas of Al clusters, thereby decreasing, both, insensitivity and effectiveness. This obstacle prevented large scale quantities to be produced at a consistent quality with desired characteristics.

The other control variable is rate of addition. It has been found that when particles are added simultaneously a clustering effect is noticed. These clusters need to be broken-up through a high shear mixing action in order for them to be evenly dispersed in the mix.

Experimental

Procedure:

When processing through a twin screw extruder one can think of it as a continuous series of batch mixes at the molecular level. By selectively designing the screw elements, one can introduce varying degrees of mixing from high shear mixing (intensive mixing) to very low shear mixing (extensive mixing). When producing PAX-3 both types of mixing are needed. Intensive mixing is required to solvate the PAX-3 into a pliable material that can flow through the extruder. Extensive mix is necessary to “fold-in” the Al particles. This mixing ensures a homogenous dispersion of Al particles without adversely coating them. The twin screw extruder also allows for greater process control through the ability of feed rate control and a greater intimacy of mixing. This ensures that the material will experience the same process history throughout the mixing process (no dead zones where material can become trapped and overworked). These processing parameters, along with temperature, feed rates and screw speed, can be determined through two methods; trial-and-error and a mathematical model provide by Steven Institute of Technology (Highly Filled Material Institute).

The use of mathematical modeling is an essential part of process safety. The mathematical model uses rheological data provided by the Rheology facility at Picatinny RDECOM-ARDEC to input key material properties into a first principle model of the twin screw extruder. This model allows the user to incorporate process limits on the extruder. These limits establish a safety envelope for the process. In order to verify the model, inert runs are made on the extruder whereby temperature and pressure profiles are gathered. This data is compared to the model to confirm predictability.

By exploring various process scenarios through the model a final screw configuration, process feeder set points, and location were determined. It was determined that the plasticizer be fed first, followed by the PAX-2A, then the solvent, and finally the Al powder. This feed order will prevent the formation of gels as mentioned above. Based upon model prediction and verification by inert process runs it was also determined that the solvent percentage should not fall below 7% in order to maintain a safe operation.

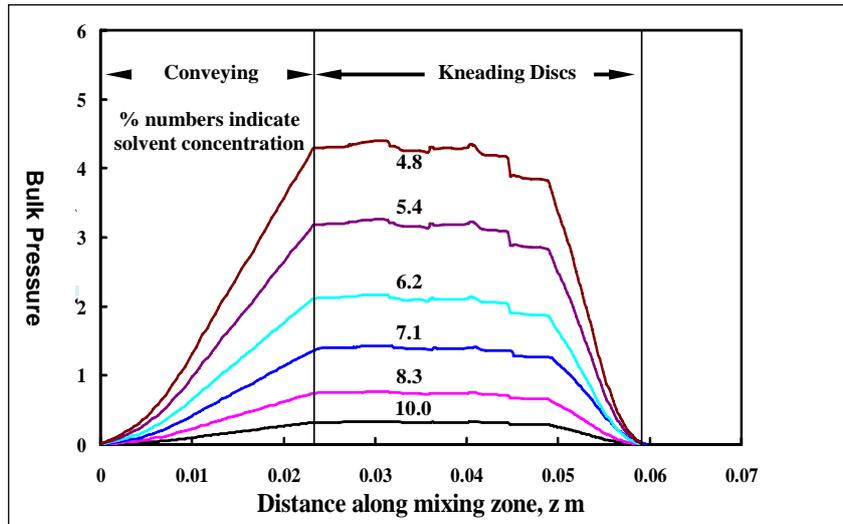


Figure 1 : Model Prediction for Bulk Pressure as a Function of Solvent Concentration

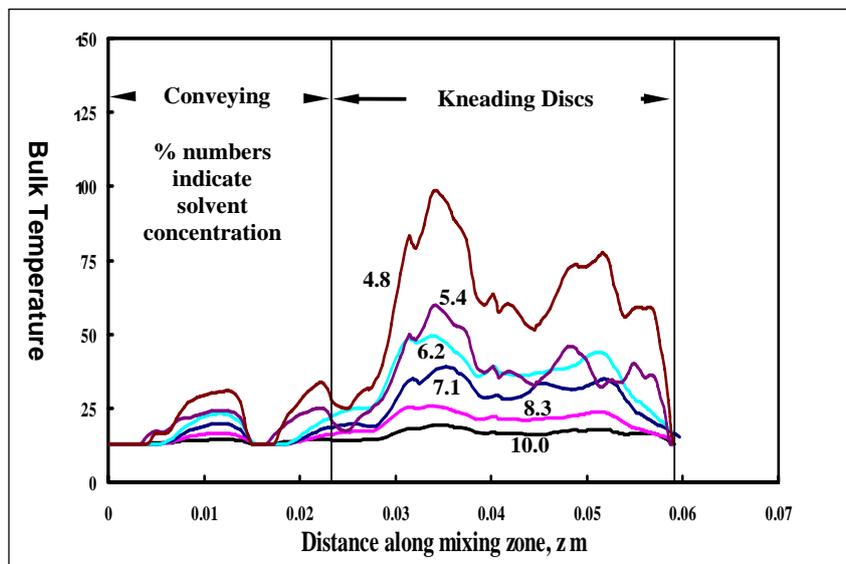


Figure 2 : Model Prediction for Bulk Temperature as a Function of Solvent Concentration

The material processed at steady state for 30 minutes. Twenty pounds of material was produced. The predicted pressure and temperatures profiles provided by the model were verified. Shut down was due to quantity-distant constraints.

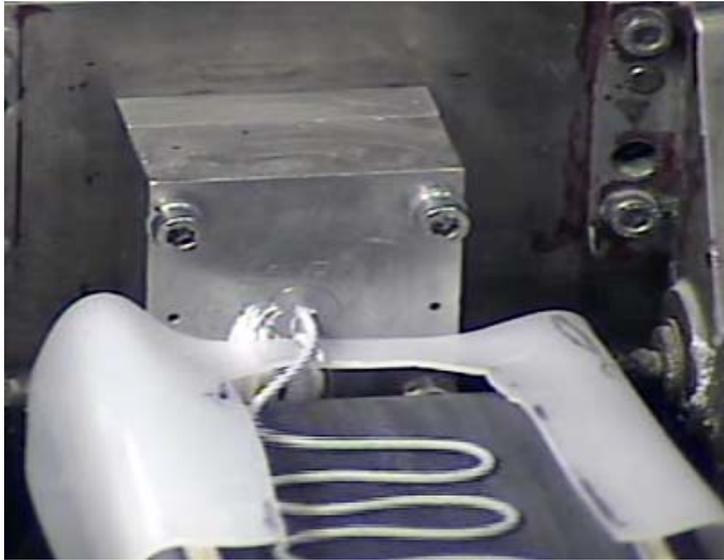


Figure 3 : Extrusion of PAX-3



Figure 4 : Granulated PAX-3

Equipment:

The experimental set-up for the processing of PAX-3 consisted of five feeders (three solids feeders and two liquid feeders), a 40 mm Baker-Perkins TSE, and appropriate ancillary units. All equipment was properly grounded and bonded to ensure electrical continuity.

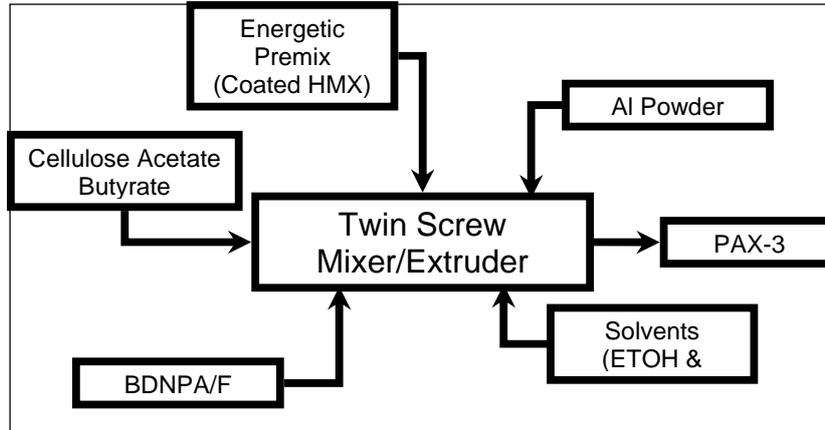


Figure 5: Process Flow Diagram For PAX-3 with Pre-blend PAX-2A

Feeder A (Cellulose Acetate Butyrate): AccuRate loss-in-weight feeder that, due to gear ratio limitation and processing parameters, was initiated and controlled through manual mode. A solid helix single screw was used for material propagation.

Feeder B (BDNPA/F): AccuRate loss-in-weight feeder in conjunction with a Zenith gear pump was used to meter a controlled amount of material to the extruder.

Feeder C (PAX-2A): AccuRate loss-in-weight feeder with an open helix single screw. This provided for greater feeding accuracy of the larger grained feed material.

Feeder D (Solvent): Accrison loss-in-weight feeder in conjunction with a Crane Chem/Meter hydraulically actuated diaphragm metering pump was used to meter a controlled amount of material to the extruder.

Feeder E (Al Powder): Controls and Metering feeder uses a twin feed screw with a horizontal agitation system. After loading the hopper, the feed material was blanketed with nitrogen in order to reduce exposure to oxygen, thus limiting a redox reaction and increasing the effectiveness of the Al powder in the final material.

Extruder: 40 mm Baker Perkins co-rotating fully intermeshing extruder with segmented screws. This extruder has five heating zones, four along the barrel and one at the die that can be set independently. This extruder has five powder feed ports and ten liquid injection ports along the barrel. The barrel is split vertically along the axis of symmetry. This allows for remote operation and a quick open in the event of an incident. This feature also allows the barrel to be open during an inert run to verify to goodness of mix.

Cone Mill: The cone is a Kemutec cone mill with an 8 mm mesh screen and ¼ inch spacer between the blade and unit.

Indexer: A pneumatically actuated indexer with eight possible bins was used to segregate samples.

Conclusions

On February 02, 2006 the TSE team produced 20lb of PAX-3 material. This material appeared to be consistent with material from batch mixes. This material processed according to the model's prediction. Testing of this material is currently underway; results are expected by end of March 2006. The current estimated cost of producing this material is approximately \$50 - \$70/hr under production conditions.

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