Twin Screw Extrusion of Aluminized Thermobaric Explosives

Mr. Michael J. Fair
E-mail: Michael.fair2@us.army.mil
Phone 1-973-724-7751

US Army
RDECOM – ARDEC
Picatinny Arsenal
Picatinny NJ, 07806-5000

Abstract

The manufacturing of advanced explosives containing large amounts of metal powders to improve performance, such as PAX-3, have proven difficult to transition into production. Current manufacturing processes have had low yield 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 base explosive, (PAX-3). The TSE team has successfully demonstrated this concept on the live formulation (02-02-06). This material was processed using a smaller concentration of green solvents in comparison to the conventional batch processing and is more uniform. The TSE method uses a base material consisting of coated HMX (PAX-2 or PAX-2A), made by conventional means, 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 to be employed 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 face of warfare today new and tailor-made insensitive explosive are needed to defeat specific threats. These new explosives contain large amounts of metal particles, adding to the overpressure. One such explosive is PAX-3. PAX-3 is a Picatinny Arsenal Explosive developed in the early 1990's. PAX-3 is the aluminized corollary to PAX-2 and PAX-2A. PAX-3 has been shown to have a greater overpressure of detonation, making it a more effective high explosive. But due to reactions with these metallic particles, it has been found to be difficult to manufacture these types of materials through conventional methods. The major factors that contribute to the difficultly in transitioning to large scale production are difficulties in controlling process variables and process parameters; temperature profile, shear rate, goodness of mix and particle dispersion. The inability to control these key variables has produced an increase in waste, thus driving up production cost.

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 batch mixing PAX-2A. With the inherent difficulties associated with producing PAX-3 by conventional means it was proposed to process PAX-3 through a twin screw extruder in order to lower cost and produce a high quality product.

Theory

In order to make PAX-3 through a twin screw extruder, one must first understand what is happening at the molecular level. The key control variables are: HMX particle size, HMX particle size distribution, order of addition, Al particle size, Al particle size distribution and time of addition. HMX and Al particle size and particle size distribution are defined in military specifications for PAX-3. These constraints reduce the number of process control variables from six to two. We will concentrate on these; order of addition and time of addition.

It has been found that these two variables are very important for a quality mix. Order of addition is an essential consideration and should not be over looked. 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 broken-up. 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. This 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. 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 proved that an end product with desired characteristics would be difficult to produce in large quantities at a consistent quality.

The other variable that can be controlled is time of raw material 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 2004 it was proposed that a continuation of the PAX-2A program be explored to make aluminized versions of PAX explosives. The objective of the program was to demonstrate that through the use of a base material (desensitized HMX), and the addition of metal particles (Al particles), one can produce a thermobaric explosive with increased insensitivity and a cost effective means of producing PAX-3.

Experimental

Procedure:

When processing through a twin screw extruder one can think of it as a series of small batch mixers in a continuous process. By selectively designing the screw elements, one can introduce high shear mixing (intensive mixing) to very low shear mixing (extensive mixing). When producing the PAX-3 formulation 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 manipulation and 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 (High Filled Material Institute).

To the TSE facility RDECOM-ARDEC the use of mathematical modeling is essential in the process safety aspect of the twin screw extruder. The mathematical model uses rheological data provided by the Rheology facility at Picatinny RDECOM-ARDEC to input key material properties into a first principal model of the twin screw extruder. This model allows the user to incorporate process limits on the extruder. This allows for a safely predicted product before live processing is attempted. 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. (See figure 1 – 3)

By exploring various possible process parameters through the model a final screw configuration and process feeder set points 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. It was also determined that the solvent percentage not fall below 7% in order to maintain a safe operation.

The material processed at steady state for 30 minutes (shut down was due to quantity-distant constraints) and the predicted pressure and temperatures profiles were verified. Twenty pounds of material was produced. (See Figure 4 – 6)

Equipment:

The experimental set-up for the processing of PAX-3 consisted of five feeders (3 solids feeders and 2 liquid feeders), a 40 mm Baker-Perkins TSE, and appropriate ancillary units. All equipment was properly grounded and bonded to ensure electrical continuity.

Feeder A (CAB): 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 using 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.

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 was used to segregate samples with eight possible bins to separate material.

Conclusions

On February 02, 2006 the TSE team produced 20lb of PAX-3 material. This material seemed 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 February 2006. The current estimated cost of producing this material is approximately $50 - $70/hr.

Figures:

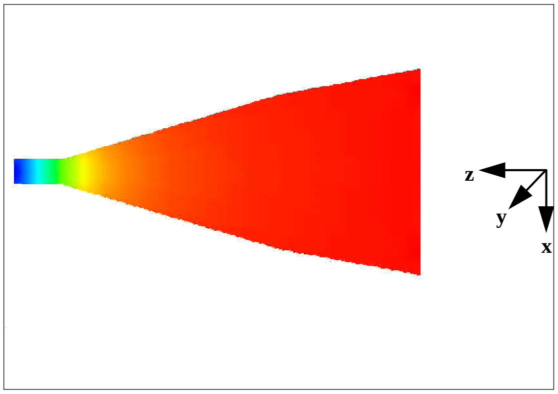

Figure 1: Model Predicted Pressure Profile of Die

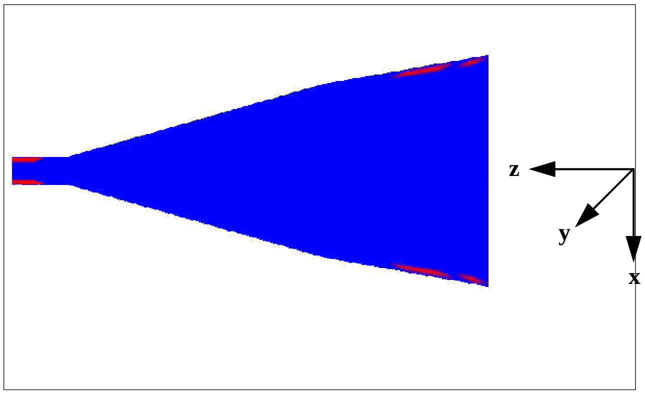

Figure 2: Model Prediction of Temperature Profile of Die

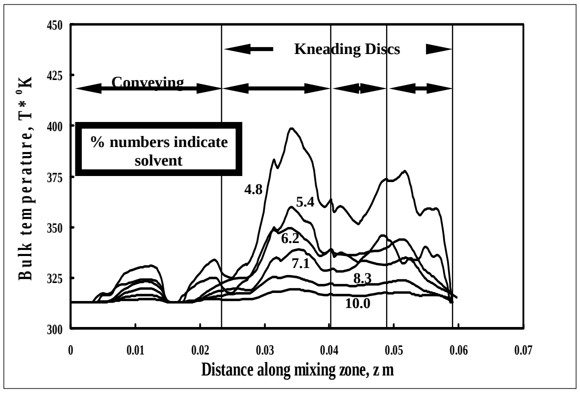

Figure 3: Model Prediction of Temperature Profile in Mixing Zone

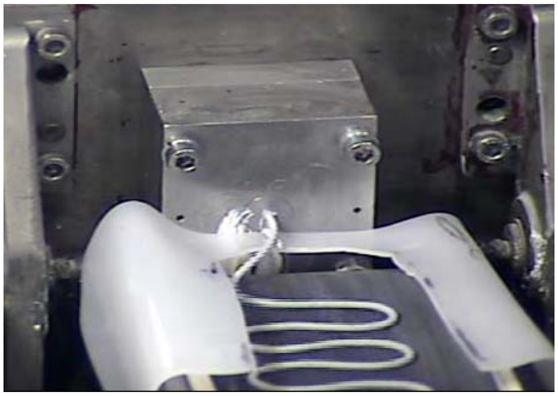

Figure 4: Extruded PAX-3

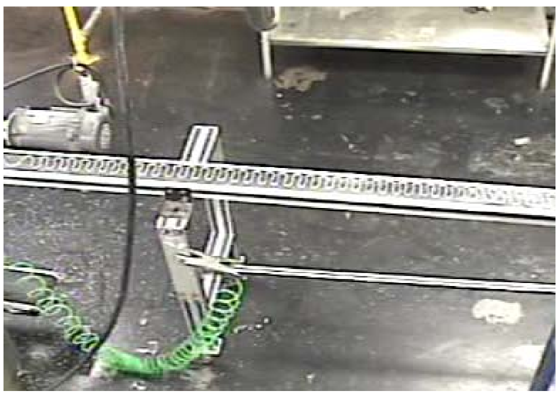

Figure 5: Extruded PAX-3 on Conveyor

Figure 6: PAX-3 Granulated