Experimental analysis on extrusion of primer composition for ignition

Ankur Yadav[1], Ganesh Nagnurwar[2], and Abhishek Sin[3]
1Pimpri Chinchwad college of engineering and research , Pune, India
2 Pimpri Chinchwad college of engineering and research , Pune , India
3 Pimpri Chinchwad college of engineering and research , Pune , India

***Abstract -* Common igniters such as black Powder, Gun powder, and boron potassium nitrate (BKNO3) are routinely employed in all calibers of gun systems. Armament Research Development Engineering Center (ARDEC) has pursued efforts to improve the ignition of propellants which has been demonstrated to be the root cause of many tribulations for propulsion systems. This leaded to the development of several extrudable nitrocellulose-BKNO3 based igniter materials that are more energetic, and exhibit smaller ignition delay times than most traditional igniters. Demonstration is done via static firing. High speed video during static CV testing has demonstrated significantly more consistent, intense, and rapid flame generation in comparison to BKNO3 pellets and other granular formulations leading to improved ignition effectiveness of the propellant bed. The method of extrusion was involved using single or twin screw extruder for the purpose of development of strands**.

I. INTRODUCTION

The ignition of the propellant bed in large caliber systems has been determined to be critical for proper performance.[1]Inadequate ignition can lead to hangfires, misfires, loss of accuracy, and catastrophic failure of the gun system. A large majority of these problems arise due to negative differential pressure waves occurring between the two ends of the chamber in the gun and can be traced back to improper ignition. Firing begins by the initiation of a small bit of primer material that is either impact or electrically sensitive. The release of the primer energy then ignites the igniter material usually situated inside a perforated metal tube in the center of the propellant bed. Ignition of the propellant bed occurs via two mechanisms. Firstly, the condensed phase material generated from the combustion of the igniter makes direct contact with the propellant bed and transfers its heat via conduction. In a complimentary process, the hot gases generated by the combustion of the igniter material travel across the propellant bed and transfer their heat to the propellant via convection.[3]This is a slower process than conduction, but doesn't seem to develop pressure differentials as readily. Attempts to isolate the actions of the condensed and gas phases on ignition were demonstrated to be inconclusive since a dynamic equilibrium exists between molecules in the gas phase and condensed phase, which allows the two phases to constantly interconvert. The importance of the condensed and gas phases of the igniter combustion products has always been controversial,[4] but the current belief is that the condensed phase plays a more critical role in ignition of the propellant bed than does the gas phase.

Traditional ignition materials include black powder and benite, with benite being a roughly 1:1 mixture of black powder and nitrocellulose. Boron potassium nitrate (BKNO3) has been used in rocket fuels for some time and is very similar to aluminum in its combustion characteristics owing to both aluminum and boron containing an outer oxide layer. This boron Oxide layer (B2O3) is thought to have a higher evaporation temperature than elemental boron. Therefore, during the combustion process, elemental boron is burning inside its oxide shell.[5]Once the oxide shell is evaporated, the rest of the boron can begin combustion with the fuel.[6] However, if there are hydrogen containing gases present during this second combustion stage, the notorious HOBO species form and prevent the boron from releasing all of its energy.In this effort, high performance igniters were formulated and examined in a static test fixture or CV firing and compared to Benite and other traditional compositions developed by using pelleting method and compression techniques using die and punch, in terms of pressure and flame generation. Formulations consisted of mixing varied amounts of boron, potassium nitrate, and nitrocellulose

II.TWIN SCREW EXTRUDER

Twin screw extrusion machines or, twin screw extruders, are the simplest example of multi-screw machines (Figure 1.). The two screws may rotate in the same direction (co-rotation) or they may rotate in opposite directions (counter or, contra-rotation). The flights of the screws may intermesh or they may not intermesh. As intermeshing, or partially intermeshing, types of machines are the most popular the discussion which follows is restricted to this type of machine.
Uses of Twin-Screw Extruders Twin-screw machines have always been popular for certain processes, for example, where there is a need for a compounding step as well as an extrusion step. This is particularly true for un-plasticized polyvinyl chloride (UPVC). This material is often stabilized against heat degradation by the use of heavy metal compounds (like organic tins, or lead) and such stabilizers are expensive
Thus, for economic reasons, the amount of these heat stabilizers must be kept as low as possible. One way of doing this is to compound and extrude in one step. This saves a further heating stage (if the material is first compounded, cooled and then re-extruded). Twin screw machines are widely used to make UPVC pipe and profiles. Today they are often used to compound other plastics, or resins, with

additives to make compounds for use in other extrusion or injection molding operations.

The co-rotating twin screw extrusion process is widely employed in chemical industries for the processing of complex fluids including various polymers, suspensions, emulsions and gels. Here we propose a new integrated modeling strategy that is based on the numerical analysis of pressure-generating extrusion elements concomitantly with the pressure-losing extrusion elements of the co-rotating twin screw extrusion process for non-Newtonian fluids under non isothermal conditions.

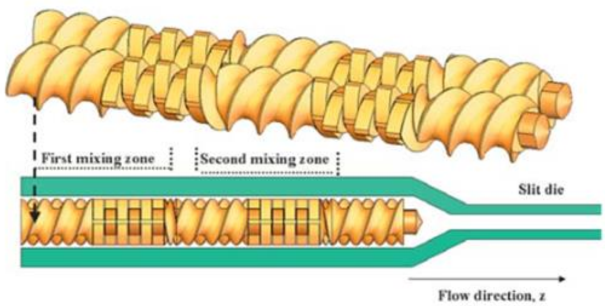


Fig: Typical screw configuration and screw and die configuration

The numerical analysis undertakes three-dimensional (3-D) finite element simulations of any multiple combinations of forwarding and reversing fully lighted screw elements with other types of elements including kneading discs staggered in the forward or reverse configurations and the die.

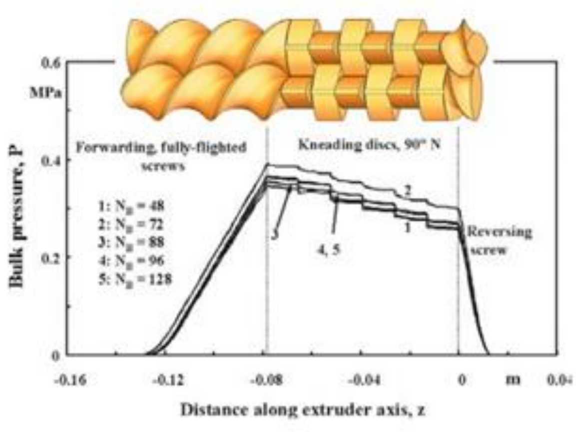


Fig: bulk pressure vs. distance along extruder axis

The abilities of the methodologies in simulating the coupled flow and heat transfer in industrially-relevant mixing sections or pressurization/die shaping are demonstrated with predictions of the degree of fill and typical velocity, deformation rate, stress magnitude, pressure distributions as functions of various operating parameters and basic twin screw extrusion geometries for a viscoplastic type generalized Newtonian fluid.

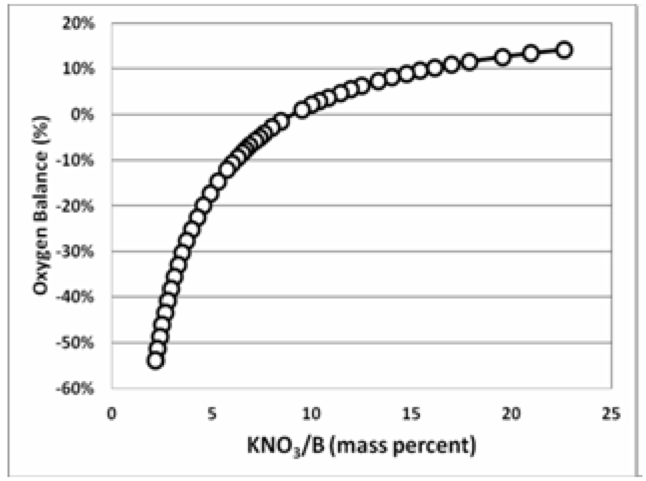


Fig: Calculated oxygen balance and flame temperature as a function of oxidizer:fuelratio.

III. EXPERIMENTAL FIRING

A static test fire fixture was designed and built to examine igniter performance. In this fixture, two pressure probes are aligned with the perforations in the igniter tube at the forward and aft ends. This provides pressure readings at two distinct points along the igniter tube and allows us to identify the potential for the formation of pressure differentials that would then be magnified in the propellant bed, leading to poor ignition. Once the igniter is initiated, two pressure-time traces are generated, one for each pressure gauge. From this output, the times to maximum pressure (Pmax) and 10% of Pmax were measured. All data was obtained from a minimum of five separate shots of each igniter type in the same strand configuration. No igniter tubes were reused for multiple shots. The formulations described below as HPI 11-10- 1, HPI 11-10-2, and HPI 11-14-1, had B:KNO3 ratios of 10:1, 10:1, and 9:1 by weight, respectively.

IV. MODELLING STUDIES

To improve upon the efficiency and performance of BKNO3 igniters, we first examined the combustion of a standard Type IV BKNO3 igniter7 using Cheetah 5.0 for thermodynamic properties determination. Type IV BKNO3 had an Oxygen Balance of -33% indicating that it is extremely fuel rich. Because of the severity of this oxygen imbalance, a study was performed on the combustion of BKNO3 igniters with various boron: potassium nitrate ratios. As demon- started in Figure on the left side, as the oxidizer (KNO3): fuel (boron) ratio is increased, there is a non-linear increase in oxygen balance (OB) which should improve the combustion characteristics. When the flame temperature produced by the igniters was examined as a function of oxidizer: fuel ratio, an interesting result was obtained. Two peak temperatures are achievable depending on the oxidizer: fuel ratio. Beyond this second peak, the flame temperature drops significantly. Since a hotter flame temperature is predicted to have better ignition effectiveness, formulations with negative oxygen balances and low KNO3: B ratios were prepared. By utilizing the thermodynamic studies as a guide, formulations were generated that contained varying amounts of BKNO3 (at different B:KNO3 ratios), along with nitrocellulose (NC). The addition of NC allowed for straightforward processing and extrusion of the igniters into a variety of desired shapes. However, the BKNO3 and NC mixtures were determined to be Unstable just by themselves, but this was resolved.8 In the following sections only the best three formulations, HPI 11-10-1, HPI 11-10-2, When the data for the static fire shots was tabulated and analyzed, certain trends became evident. As shown in Figure 2, the magnitude of Pmax was comparable between Benite and the three BKNO3 analogues. The standard deviation of the magnitude of Pmax (ΔPmax) was also the same between all samples. As an estimate of how quickly the formulations ignited, we chose to measure the time it took to reach 10% of Pmax (t2). The three BKNO3 analogues had slightly shorter t2 times than Benite, and their standard deviations (Δt2)were extremely small in comparison. This clearly demonstrated that the BKNO3 analogues began the ignition process more consistently and more rapidly than Benite. When the time interval from trigger pull to Pmax (t5) was examined, it became evident that the three BKNO3 analogue igniters were about ~30% faster than Benite, and once again significantly more consistent.

Another time interval we examined was the interval between Pmax and 10% of Pmax, and is designated as t6. This is a measure of how quickly the igniter releases its energy into the propellant bed, and relates to ignition effectiveness. The values of t6 for the three BKNO3 analogues were half of Benite’s. This indicated that the igniters released their energy twice as fast as conventional igniters.

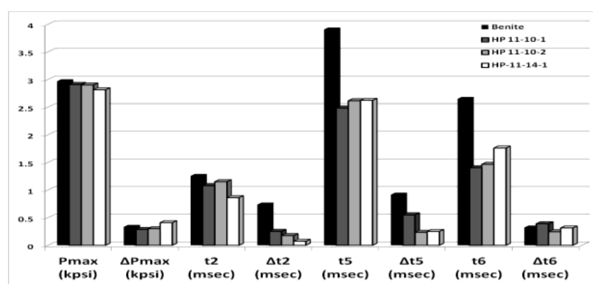
To compliment the pressure readings along the igniter tube and ascertain the flame generating effectiveness, high speed video was also employed during the igniter static fire testing.

A surprising result was attained during the baseline establishment using Benite at ambient temperature. As shown in Figure below by the dark boxes, early on in the ignition event of Benite, flames were absent from several ports towards the aft end that should have already ignited. This would cause an uneven ignition of the propellant bed which certainly would lead to the formation of negative pressure differentials in the gun system. This condition was exacerbated under cold conditions, and alleviated under hot conditions to examine the effects of the forward portion of the igniter tube igniting the propellant bed before the aft portion, we performed a Frazier Nash GUN (FNGUN) modeling study.

FNGUN is a one dimensional ballistics code that allows the determination of pressure time traces and permits the inputting of flame spreading velocity. Using a 120mm model we had generated previously for tank ammunition, we examined the ignition effects when the flame spreading was uniform and instantaneous from the igniter tube as shown Fig. No negative pressure differentials are generated in this case. For the staged ignition study, we selected a point halfway up the igniter tube from which the flame spreading velocity was four times greater than at the aft end to mimic what we saw in the high speed video. A simulation was performed where apropellant bed was thus ignited and is presented in Figure B. Severe negative pressure differentials were generated, and were well beyond the acceptable limits for a gun system. This finding further confirmed the critical role that ignition plays in large caliber gun system performance.

V. STATIC TEST ANALYSIS

In Figure below, a better view of the flame spreading is observed for the BKNO3 analogue HPI 11-10-1. After ignition the vents burst sequentially from the aft end towards the tip very rapidly. At 1.3 milliseconds a significant amount of flame is generated. At 4.7 milliseconds, condensed phase particles are seen flying out of the flame front and this continues for 2 milliseconds. This intensity of particle generation was not observed in Benite. The BKNO3 analogues seem to generate more flame and do it more rapidly and consistently than the Benite and other



conventional igniters.

Fig: *Figure.Comparison ofP_{max}, t_2,t_5,andt_6 forBeniteandtheBKNO$_3$ basedigniters*

VI. CONCLUSION

By employing the lessons learned from the modeling of BKNO3 analogues in Cheetah 5.0, igniter formulations were produced that exhibited significantly improved performance relative to Benite. Benite was found to have significant shot to shot variability in terms of pressure and time, except at hot temperatures. High speed video of these ignition events indicated that early in the ignition process, often times the forward end of the igniter tube would have more flame jet output than the aft end. This would lead to undesirable combustion of the propellant bed beginning in the middle of the cartridge, and definitely lead to the generation of pressure waves. Extrudable BKNO3 analogue igniters were also examined on the igniter static test fixture. They were able to achieve Pmax faster than Benite with less variance in ignition delays and output pressures than Benite, thus demonstrating that the analogue igniters are more consistent. High speed video of the ignition events also demonstrated more hot particle and flame generation in the BKNO3 analogue igniters in comparison to Benite. The BKNO3-NC based igniters appear to provide a much more consistent and powerful ignition event.

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