TSE Processing of Functionally Graded Energetic Materials

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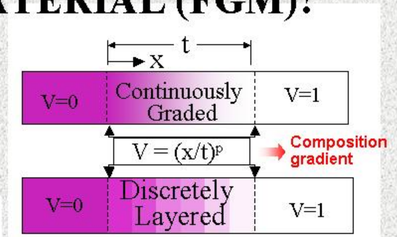
WHAT IS A FUNCTIONALLY GRADED MATERIAL (FGM)?

- Components featuring gradual transition in microstructure and/or composition



Can define architecture of FGM through p and t!

MOTIVATION AND NEEDS FOR FGEMS

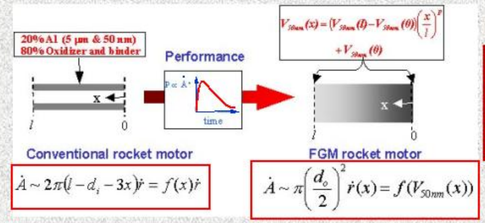
MOTIVATION

Develop a new approach for achieving a wider range of performance in energetic systems, such as rocket motors, by applying FGM concepts to new twin-screw extrusion technology for continuous processing of energetic materials

NEEDS

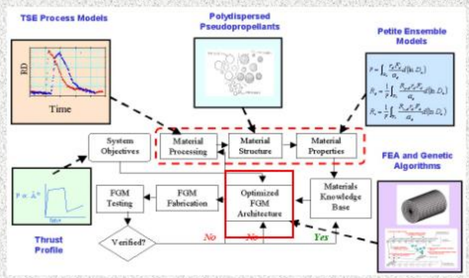
- **Dynamic Processing Model for Predicting Effects of Transient Operating Conditions on the Evolution of Graded Microstructures**
- **Property and Performance Models for Predicting Variable Performance**
- **Integration of Processing, Property, and Performance Models with Mathematical Optimization Techniques into an Inverse Design Procedure**

FGEM CONCEPT FOR ROCKET MOTORS



Can tailor burn rate performance through material distribution instead of geometry!

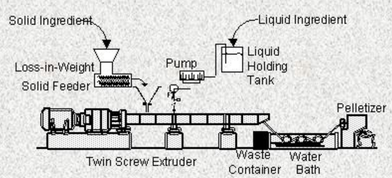
INVERSE DESIGN PROCEDURE FOR FGEMs



Can determine optimal material distribution through a closed loop design process centered around FGM architecture!

TWIN-SCREW EXTRUSION (TSE) PROCESSING OF FGMs

Can dynamically vary feed ingredients and operating conditions to create gradient architecture!

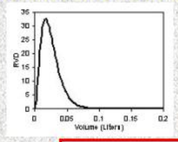


Propellant Formulation will Utilize 3 Solids Feeders and 2 Liquids Pumps

- **28 mm Lab-Scale Extruder — UMD/College Park**
- **40 mm Pilot-Scale Extruder — NSWC/IHDIV**

PROCESSING MODELING (*Residence Volume Distributions*)

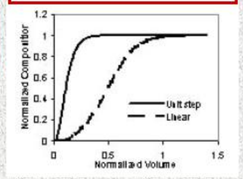
Can Characterize the Effects of Screw Geometry, Material, and Process Conditions of TSE through RVD!



Transient operating conditions

$$f[z(\nu)] = \int_0^{\dot{\nu}} g(\nu-\nu')h(\nu')d\nu'$$

Can predict gradient microstructure using RVD convolution!



RVD Model: $g(\nu) = \frac{a^3}{2}(\nu-\nu_d)^2 e^{-a(\nu-\nu_d)}$

COMBUSTION PROPERTIES (*Petite Ensemble Model*)

$$\dot{r} = m''_{ox}/\rho_p$$

$$m''_{ox} = m''_{ox}\left[3\left(\frac{h}{D_o}\right)_+^2 + 3\left(\frac{h}{D_o}\right)_- + 1\right]$$

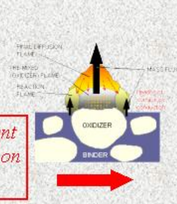
$$m''_{ox} = A_{ox}\exp\left[-\frac{E_{ox}}{RT_{s,ox}}\right]$$

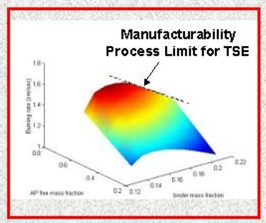
$$\left(\frac{h}{D_o}\right)_\pm = f(r_{ox}, \tau_{ign}, D_o)$$

$$r_{ox} = m''_{ox}/\rho_{ox}$$

$$\tau_{ign} = \frac{C_{ign}D_o^{\delta_o+1}}{p\delta_p}$$

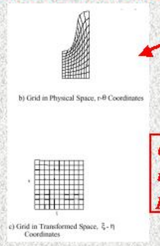
Gradient effects on p, T



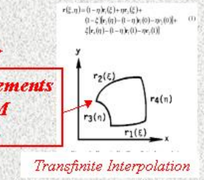


PERFORMANCE MODELING (*Finite Element Analysis*)

3-D Euler CFD code



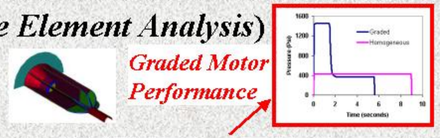
Graded elements using PEM properties



Transfinite Interpolation

Partial Differential Equations

Graded Motor Performance



SUMMARY

1. **New dynamic process models developed based on convoluting Residence Volume Distributions with transient operating conditions for predicting graded microstructures**
2. **New performance models of FGEMs based on Finite Element Analysis using Petite Ensemble Models**
3. **Integration of RVD processing, PEM property, and FEA performance models with Genetic Algorithm optimization technique into an Inverse Design Procedure for FGEMs**