TEXAS TECH UNIVERSITY
Department of Mechanical Engineering

Ph.D. Defense Announcement

Pre-stressing Aluminum Powder to Promote Reactivity

by

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Abstract

Aluminum powder is a key ingredient in many propulsion and munition systems. However, as a fuel it is plagued by slow reaction rates and incomplete reactions. Pre-stressing aluminum (Al) particles by annealing and quenching alters dilatational strain and is linked to increased particle reactivity. The quenching rate associated with pre-stressing is a key parameter affecting the final stress state within the Al particle, with faster quenching rates theoretically favoring a higher, more desirable stress state. Nano and micron scale Al particles are annealed to 300°C, then quenched at different rates, mixed with an oxidizer, and the resulting mixtures are examined under low-velocity, drop-weight impact conditions, as well as high-velocity, powder gun impact conditions. Annealed and quenched powders show increased impact ignition sensitivity (i.e., a decrease in ignition energy). Low-velocity initiation energy decreases by nearly an order of magnitude for the pre-stressed aluminum (compared to untreated samples). Pressurization data also demonstrates significant improvement in reaction rate and combustion efficiency. Synchrotron powder X-ray diffraction (PXRD) data shows order-of-magnitude differences in dilatational strain between untreated and pre-stressed aluminum particles. Results are rationalized with the help of a simple mechanical model that takes into account elastic stresses, creep in the alumina shell and delamination of shell from the core. The model predicts different shell failure mechanisms at different quench rates: delamination from the core at higher quench rates vs increased compressive stress at lower quench rates. At higher velocities (850-1250 m/s), pre-stressed materials demonstrate significant differences in flame spreading after impact as well as pressurization during and after impact. Flame spread data and pressurization for Al quenched at different rates are both consistent with core-shell delamination and shell strength after annealing. Under thermal initiation, single particles of pre-stressed Al at different quenching rates demonstrated shorter ignition delays and burn times compared to untreated Al, indicating that pre-stressing reduces the diffusion barrier through shell cracking or energy release from strain energy during heating. These studies have established a promising, bulk metallurgical process to mechanically alter aluminum particle properties. Such alterations have an impact on aluminum reaction mechanism and reactivity. Pre-stressing fuel particles is a promising method to improve how much stored chemical energy can be harnessed from metal fuel particles.