Resodyn™ ACOUSTIC MIXERS

RAM and the Rise of Printed Energetics

Five studies, four energetic categories, and a U.S. Army patent point to one enabling mixing technology.

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OVERVIEW

For as long as energetics manufacturing has existed, grain and charge geometry have been limited to whatever a mold could produce. Additive manufacturing promised something better, internal geometries, gradient structures, and shapes no cast could achieve. Every attempt ran into the same wall. Propellant, pyrotechnic, and explosive feedstock need solids loadings above 60 percent, sometimes past 85, with viscosities that have long been difficult for safe, homogeneous bladed mixing.

A growing body of peer-reviewed research, spanning five years and covering multiple energetic categories, now backed by a granted U.S. patent, has converged on the same innovative solution. ResonantAcoustic® Mixing turns these formulations into printable feedstock. Bladeless, fast, and consistent mixing transformed 3D-printed energetics from research curiosity to patented manufacturing method. The next generation of energetics now includes additive manufacturing.

Solution

- ResonantAcoustic® Technology
- Bladeless Mixing to 85% Solids Loading
- Printable Ink in Minutes, Not Hours
- Validated Across Four Energetic Categories

Achievement

- Patented by U.S. Army Research Laboratory
- Five Studies Published, 2017 to 2022
- Propellant Printed at 85% Solids Loading
- Chromate Free Pyrotechnic Delay Validated

CHALLENGES

Additive manufacturing offered a path around limited molds and suboptimal gemoetries, but the materials themselves stood in the way. Propellant, pyrotechnic, and explosive feedstock all require solids loadings well above conventional printing limits, with solids loadings reaching 85 percent [1] and viscosities that conventional mixing struggles to blend consistently. Pyrotechnic delays carried a parallel problem: pressing reactive powder into rigid metal housings limited configurability and left a reliability gap. [3] Reactive and explosive inks added a third challenge, dispersion fine enough for micro-scale resolution without sacrificing the crystal structure or the required sensitivity for predictable performance. [4][5]

Conventional mixing couldn't close these gaps safely. Bladed and impeller mixers are prone to contact points between the blade and vessell wall, where energetic materials are most likely to ignite. Inhomogeneous mixing, common with high viscosity blends in conventional mixing, degraded print quality directly and raised reliability issues before the feedstock ever reached the print head. A sealed, blade-free mixing method was needed that could achieve printable consistency and final product quality without safety concerns. ResonantAcoustic® Mixing, already proven in energetics manufacturing, meets all of the necessary criteria for additive manufacturing energetics safely, with consistent homogeneity.

Patented by the U.S. Army

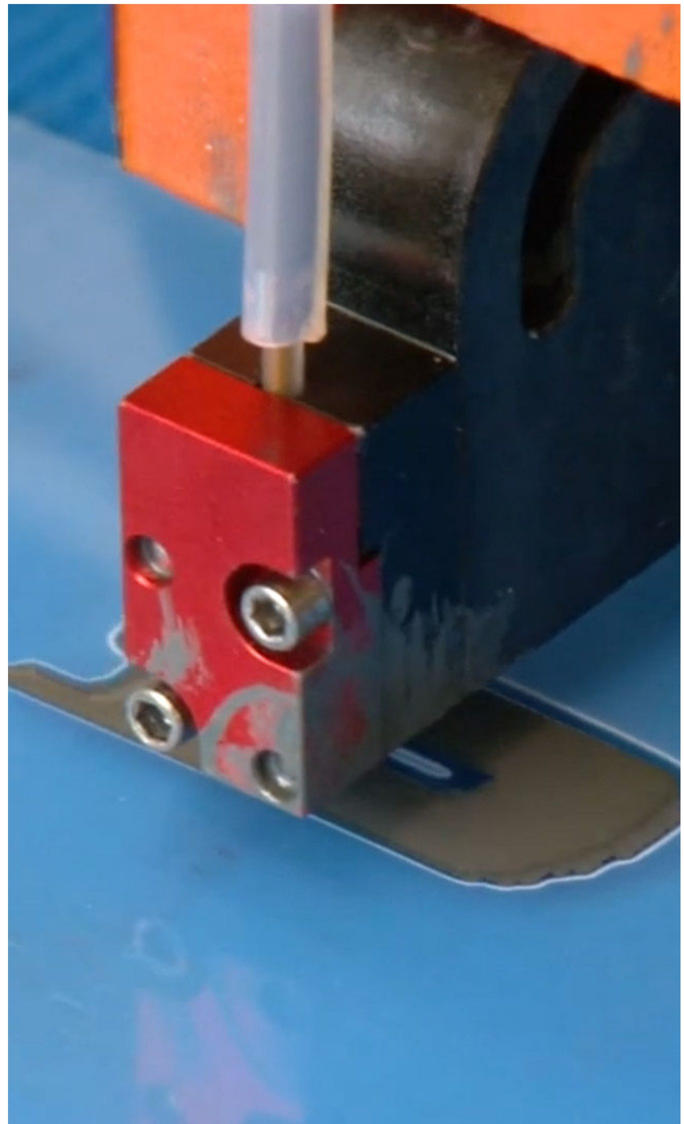
In 2021, the U.S. Army Research Laboratory patented a hybrid process pairing additive manufacturing with ResonantAcoustic® Mixing [6]. A soluble negative, printed in the shape of the grain's internal channels, is placed in a RAM mixer with uncured propellant. The propellant densifies around the negative, which dissolves away, leaving those channels hollow inside a propellant grain no mold could cast. The result: a surface-area-to-mass-fraction-burned ratio of roughly 5, more than double the 2 achieved by casting, with a 5% muzzle velocity gain for tank guns and 10%+ for indirect-fire weapons. RAM also enables solvent-free formulations with zero energetic waste.

Conceptual illustration only, not a literal reproduction of patent process.

SOLUTION

Propellants

At Purdue University, McClain, Gunduz, and Son solved a problem the industry had lived with for decades: propellant grain geometry was limited to whatever a mold could produce. Their direct-write AM system printed ammonium perchlorate composite propellant at 85 percent solids loading across two binder systems. Hand mixing alone couldn't wet the formulation to a printable state. RAM finished the job, three 3-minute cycles at 80g for the HTPB binder, 2-minute cycles at the same acceleration for the UV-curable version. Printed strands held void content comparable to cast samples, and burn testing at 10.34 MPa confirmed combustion consistent with cast propellant, confirming grain structures not previously possible to manufacture. [1] The same lab applied RAM-mixed formulations, 40-gram batches run for three 3-minute cycles at 80g, to 3D-printed silicon carbide rocket nozzles, where ordinary printable thermoplastics deform well below real exhaust temperatures, and the RAM-mixed formulation stayed printable for several days without its properties drifting, a stability window hand mixing doesn't offer. [1]



Purdue reseachers create nanothermite ink for 3D printing. The printed reactive ink burns in a predictable path and supports advanced design of energetics.

Pyrotechnics

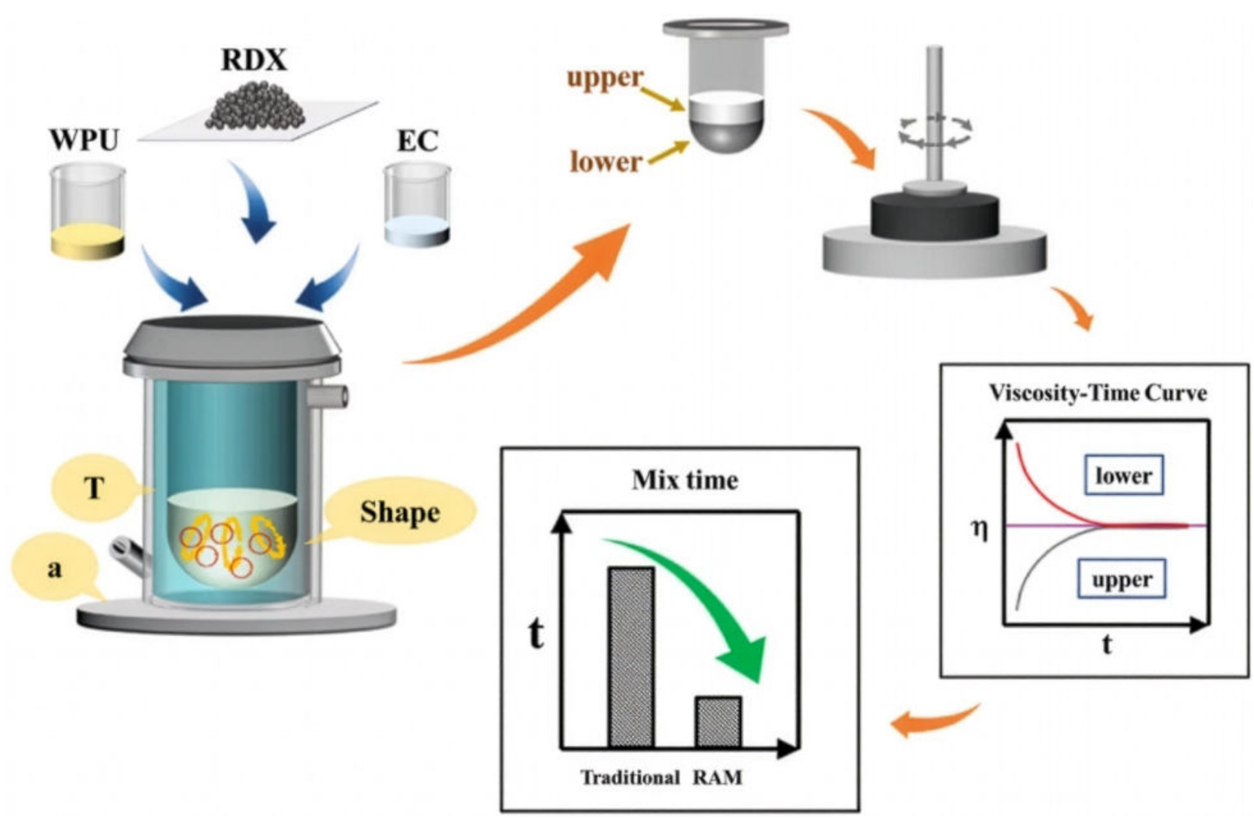
At South Dakota School of Mines and Technology, Walters and Groven took on the decades-old standard T-10 pyrotechnic delay, pressed into a rigid metal housing, a design that limits configurability and carries a documented reliability problem, with a barium chromate component that is environmentally undesirable. They mixed three boron-based dry powder systems with RAM, the baseline $B/BaCrO_4$, formulated at 14.6 weight percent boron to 85.4 weight percent barium chromate, alongside chromate-free candidates barium molybdate and strontium molybdate, at 60 to 70 weight percent solids loading in a Methocel gel matrix that held particles stable through mixing and deposition. Each formulation was mixed with RAM at 60g intensity in three 1-minute cycles with a 1-minute pause between. Combustion testing, including burning rate, gas generation, and XRD analysis of combustion products, confirmed the printed molybdate formulations as viable, chromate-free replacements. [3]

Reactive Inks

At Purdue, researchers published one of the earliest proofs in this field, in 2017, using a LabRAM to safely prepare fully reactive inks inside a single nozzle assembly. An aluminum/copper-oxide nanothermite suspension, loaded at 6 percent volumetric solids in a DMF and PVP carrier, was mixed directly inside a syringe at 80 percent intensity for 16 minutes, inverted at the halfway point. Securing this pre-filled syringe to a custom PTFE holder for inkjet printing skipped a separate, hazardous material transfer step between mixing and deposition. A five-layer printed sample showed clean ignition propagation through the structure, establishing a benchmark that later propellant work built on, with a manufacturing route directly applicable to initiators and micro-scale thrusters. [4] Ultimately, this demonstrated that RAM could safely bridge the gap between high-hazard energetic blending and precise additive manufacturing by serving as mixing directly in the printing reservior.

Explosive Ink

At North University of China, Zhang, An, Mu, Cui, Cheng, Ye, and Wang addressed the secondary explosives side of this story: trace, high-solids RDX-based explosive ink, where poor mixing consistency and material waste had limited production. Combining RAM with rheological apparent viscosity analysis, they found mixing acceleration and container shape governed efficiency, while temperature sensitivity rose sharply between 45 and 60 degrees Celsius compared to the 30 to 45 degree range, a distinction that matters for safe scale-up. Under the optimized process, ink prepared in just five minutes, with the finished product showing almost no change in crystal shape, thermal properties, or sensitivity compared to conventional paddle stirring, a result with direct relevance to micro-charge production and detonator train manufacturing, where consistency at small batch sizes is critical. [5]



Under the best preparation process route, the ink could be prepared in only 5 min with RAM. [5]

CONCLUSION

Five published studies spanning 2017 to 2022, four energetic applications, and one granted U.S. patent point to the same conclusion. This reflects a sustained, five-year body of work, much more than a single promising result: foundational reactive-ink printing in 2017 [4], propellant and pyrotechnic demonstrations following in 2019 [1][2][3], a secondary explosive ink as recently as 2022 [5], and a U.S. Army Research Laboratory patent making RAM-enabled printing official manufacturing intellectual property. [6] The publications carry their own weight, Proceedings of the Combustion Institute, ACS Sustainable Chemistry & Engineering, Journal of Applied Physics, Journal of Materials Research, each is a serious peer-reviewed venue in its field. As additive manufacturing of munitions moves from laboratory demonstration toward fielded production, RAM has become the processing step the entire approach depends on.

Contact Resodyn Acoustic Mixers, Inc. to discuss how RAM can transform your energetic blending for Additive Manufacturing.

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CITATIONS

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