PHASE 1 TECHNICAL & COMMERCIAL VALIDATION

Recycled Mattress Materials to Cementitious Composites

Post-consumer polyurethane foam + textile fibers for 3D-printed and prefabricated concrete products

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Prepared for **Mattress Recycling Council Research Program**

September 2026

Executive Summary

Phase 1 established a viable processing-to-printing pathway for recovered mattress polyurethane foam and textile fibers in cementitious composites. The work evaluated material intake and preprocessing, cementitious formulation, robotic extrusion, mechanical performance, acoustic response, durability screening, economics, and initial commercialization pathways.

20 vol%
Design sand volume removed
2,500 g → 2,000 g sand

~5 vol%
Chopped textile (loose-bulk basis)
20 g ≈ 178.4 cm^3 in a ~3.57 L batch

+52.4%
28-day fiber mix compression
5,363 vs. 3,520 psi

-12.65 dB
Large-chunk acoustic core
20–50+ mm foam, average vs. control

Primary outcome

The **tested hybrid fine-foam formulation**, consisting of 1–5 mm shredded PU foam plus micronized PU foam, demonstrated a viable direct-printing pathway while maintaining approximately control-level 28-day mechanical strength and reducing specimen density.

Chopped textile provided a separate reinforcement mechanism and substantially increased compression, flexural strength, and splitting tensile strength.

Larger foam chunks demonstrated value as **lightweight and acoustic internal fill**, allowing coarser recovered foam fractions to be utilized without unnecessary fine grinding.

Executive Summary - Phase 1 Results.

Phase 1 area	Result
Feedstock preparation	Shredding, washing, drying, screening, and coating procedures established for repeatable lab and prototype processing.
Printability	All four evaluated mix families were reported as printable; foam-dominant and combined mixes showed strong shape retention and low height variation.
Mechanical performance	Fiber-dominant and combined formulations materially outperformed the control at 28 days in compression, flexure, and splitting tensile strength.
Acoustic response	Particulate foam reduced average measured sound level by 7.2 dB vs. control; a foam-chunk core averaged 12.6 dB below control.
Commercial pathway	Work focused on acoustic panels / sound barriers and prefabricated non-structural architectural components.

Phase 2 direction. *Scale the formulation, extend durability validation, demonstrate pilot-scale additive manufacturing, and develop unit economics and commercialization plans for representative products.*

Project Objective & Technical Approach

The project addressed a practical recycling problem: mattress foam and textiles need higher-value end markets, recovered feedstocks vary physically, commercial applications must absorb meaningful material volume, and the resulting products need a credible economic pathway.

Phase 1 objective

Convert recovered mattress polyurethane foam and textile fibers into controlled cementitious feedstocks suitable for printable acoustic products and prefabricated non-structural components, then validate whether the materials could meet defined process, performance, and commercialization criteria.

Material pathway

Step 1	Step 2	Step 3	Step 4	Step 5
Receive & inspect	Size reduction / conditioning	Cementitious formulation	Robotic deposition	Durable product

Particle -size pathways

Recovered fraction	Approx. size	Primary pathway
Micronized foam	~100 µm	Fine-particle packing within printable cementitious systems
Fine foam	~1–5 mm	Printable cementitious composite development
Intermediate foam	~5–20 mm	Lightweight / acoustic aggregate screening
Large foam chunks	~20–50+ mm	Hollow-core / acoustic cavity fill
Textile fiber	~10–20 mm chopped; ~12 mm target	Reinforcement in cementitious composite

Feedstock preparation

The Phase 1 process included: Incoming material inspection; Contaminant removal; Foam shredding and particle-size control; Textile chopping to approximately 12 mm; Textile washing and rinsing; Drying to controlled moisture; Screening and labeling; Dry mineral-coating treatment used as a formulation-development step to support material dispersion and cementitious compatibility

Larger foam can be difficult to disperse and may increase bridging, clogging, voids, and extrusion inconsistency. Controlled 100 microns – 5 mm foam provides more uniform dispersion, more predictable volumetric replacement, better pumpability, and more consistent bead formation.

Formulation & Robotic Printing

Four formulations were evaluated: a control, a textile-fiber formulation, a foam formulation, and a combination formulation. Textile mixes used approximately **12 mm chopped mattress fiber**. Foam-containing mixes used a **hybrid 10 g foam addition composed of 5 g mechanically shredded 1–5 mm mattress PU foam plus 5 g RoCo micronized PU foam** to improve packing density.

Ingredient	Control	Fiber Mix	Foam Mix (50/50)	Combo Mix	Function
Portland cement	2000 g	2000 g	2000 g	2000 g	Primary binder
Fine sand	2500 g	2300 g	2000 g	1980 g	Structural aggregate
Limestone flour	900 g	900 g	900 g	900 g	Filler / print smoothness
Metakaolin	120 g	120 g	120 g	120 g	Strength / durability
PCE superplasticizer	5 g	5 g	5 g	5 g	Flow control
HPMC	3 g	3 g	3 g	3 g	Anti-sag / stability
Calcium formate	10 g	10 g	10 g	10 g	Mild accelerator
Aluminum sulfate	5 g	5 g	5 g	5 g	Main accelerator
Water	860 g	860 g	860 g	860 g	Hydration
Chopped fiber (~12 mm)	0 g	20 g	0 g	20 g	Crack-bridging reinforcement
Foam (50% 1-5 mm, 50% micronized)	0 g	0 g	10 g	10 g	Lightweight aggregate / acoustic porosity

Recycled-material loading calculations

The table below shows how the tested mass additions translate to volume percentages using the appropriate density basis for each recycled fraction.

Item	Equation / basis	Result	Meaning
Design sand removal (Foam)	(2,500 g − 2,000 g) / 2.70 g/cm^3, relative to original 2,500 g sand	185.2 cm^3 removed from 925.9 cm^3 original sand = 20.0 vol%	Design sand-removal calculation
1-5 mm foam occupied volume	5 g / 0.064 g/cm^3	78.1 cm^3 = ~8.4% of original sand volume	Occupied volume of the 1–5 mm shredded fraction
RoCo micronized foam occupied volume	5 g / 0.140–0.175 g/cm^3	28.6–35.7 cm^3 = ~3.1–3.9% of original sand volume	Occupied volume of the micronized fraction
Total foam occupied volume	5 g shredded + 5 g micronized	106.7–113.8 cm^3 total = ~11.5–12.3% of original sand volume	Actual occupied foam volume added by the hybrid 10 g blend
Textile loose-bulk bases	20 g / 0.112 g/cm^3 (≈7 lb/ft^3)	178 cm^3; corresponds to ~5 vol% in a ~3.57 L batch	How the nominal ~5 vol% textile value was reached
Textile true-solid basis	20 g / 1.2 g/cm^3	16.7 cm^3 ≈ ~0.9 vol% of dry-constituent absolute volume	Alternative true-solid calculation

Printability and dimensional stability

Mix	Vertical slump	Spread	Avg. bead width	Width CV	Height CV	Result
Control	0.73 in	3.45 in	42 mm	5.00%	1.55%	Printable
Fiber dominant	0.28 in	3.22 in	37 mm	7.50%	1.67%	Printable; dimensional-CV target not met
Foam dominant	0.22 in	3.20 in	39 mm	2.50%	1.45%	Printable
Combo	0.26 in	3.22 in	38 mm	5.00%	1.53%	Printable

Mechanical Performance

Mechanical testing compared the control and recycled-material formulations at 7 and 28 days using compressive, flexural, and splitting-tensile measurements. The project report references ASTM C39, ASTM C1609, and ASTM C496 as the corresponding mechanical test methods.

Mix / age	Compression	Δ vs. Control	Flexural	Δ vs. Control	Splitting tensile	Δ vs. Control
Control - 7 day	2,625 psi	Baseline	362 psi	Baseline	305 psi	Baseline
Control - 28 day	3,520 psi	Baseline	410 psi	Baseline	387 psi	Baseline
Fiber dominant - 7 day	3,650 psi	+39.0%	477 psi	+31.8%	331 psi	+8.5%
Fiber dominant - 28 day	5,363 psi	+52.4%	585 psi	+42.7%	563 psi	+45.5%
Foam dominant - 7 day	2,450 psi	-6.7%	334 psi	-7.7%	300 psi	-1.6%
Foam dominant - 28 day	3,450 psi	-2.0%	395 psi	-3.7%	378 psi	-2.3%
Combo - 7 day	3,430 psi	+30.7%	440 psi	+21.5%	325 psi	+6.6%
Combo - 28 day	5,180 psi	+47.2%	525 psi	+28.0%	528 psi	+36.4%

Fiber - 28 day

+52.4% compression
+42.7% flexural
+45.5% splitting tensile

Foam - 28 day

-2.0% compression
-3.7% flexural
-2.3% splitting tensile

Combo - 28 day

+47.2% compression
+28.0% flexural
+36.4% splitting tensile

Interpretation. *The fiber-dominant formulation delivered the highest reported 28-day compressive, flexural, and splitting-tensile strengths. The combined formulation also substantially exceeded the control while incorporating both recovered foam and textile fiber. The foam-dominant mix remained close to the control in strength while reducing specimen mass.*

Density and specific compressive strength

Mix	28-day weight	Δ vs. Control	Density	Compression	Specific Strength	Δ vs. Control
Control	3.25 kg	Baseline	1.97 g/cc	3,520 psi / 24.27 MPa	12.32 MPa·cc/g	Baseline
Fiber dominant	3.26 kg	0.3% heavier	1.98 g/cc	5,363 psi / 36.98 MPa	18.68 MPa·cc/g	+51.6%
Foam dominant	2.96 kg	9% lighter	1.79 g/cc	3,450 psi / 23.79 MPa	13.29 MPa·cc/g	+7.9%
Fiber + foam	3.01 kg	7.4% lighter	1.82 g/cc	5,180 psi / 35.71 MPa	19.62 MPa·cc/g	+59.3%

Specific-strength calculation

Control example: 3,520 psi × 0.00689476 = 24.27 MPa
Specific strength: 24.27 MPa ÷ 1.97 g/cc = 12.32 MPa·cc/g

Interpretation: *The fiber mix delivered the highest absolute 28-day strengths, while the foam mix maintained near-control strength at 8.9% lower weight. The combo mix provided the best overall balance, with +47.2% compressive strength, 7.4% lower weight, and the highest specific strength at 19.62 MPa·cc/g (+59.3% vs. control).*

Acoustic & Durability Screening

Acoustic response

The acoustic screening measured sound levels across 125–4,000 Hz. Both recycled-foam configurations reduced measured sound levels relative to the control across the reported frequency range.

Configuration	**Control**	**Particulate foam dominant**	**Reduction vs. Control**	**Internal foam-chunk core** *(Added inside of particulate)*	**Reduction vs. Control**
125 Hz	82.30 dB	77.30 dB	5.0 dB	68.30 dB	14.0 dB
250 Hz	90.10 dB	84.10 dB	6.0 dB	80.20 dB	9.9 dB
500 Hz	83.60 dB	76.20 dB	7.4 dB	72.00 dB	11.6 dB
1000 Hz	71.40 dB	63.70 dB	7.7 dB	58.40 dB	13.0 dB
2000 Hz	56.30 dB	48.00 dB	8.3 dB	41.20 dB	15.1 dB
4000 Hz	60.40 dB	51.40 dB	9.0 dB	48.10 dB	12.3 dB
Average	74.02 dB	66.78 dB	7.23 dB	61.37 dB	12.65 dB

The foam-chunk core produced the strongest acoustic response, averaging 12.6 dB below the control. This supports a secondary material pathway in which larger foam fractions can be used inside hollow or acoustic products rather than being ground to extrusion-grade particle size.

Durability screening

The Phase 1 report includes UV and freeze–thaw screening after 28-day cure. The reported specimens showed no visible surface damage during the initial screening. Fiber-dominant specimens retained modestly higher load capacity than the control after both exposure protocols, supporting further durability validation in Phase 2.

Exposure	Mix	Mass change	Visible / surface damage	Nominal compression
UV	Control	-1.92%	Slight whitening; no surface damage	1,337 psi
UV	Fiber dominant	-3.35%	Slight whitening; no surface damage	1,464 psi
UV	Foam dominant	-1.68%	Slight whitening; no surface damage	1,230 psi
UV	Combo	-3.10%	Slight whitening; no surface damage	1,428 psi
Freeze–thaw	Control	0%	None	1,257 psi
Freeze–thaw	Fiber dominant	-3.80%	None	1,341 psi
Freeze–thaw	Foam dominant	-1.50%	None	1,168 psi
Freeze–thaw	Combo	-2.80%	None	1,289 psi

Fiber-dominant specimens retained higher nominal compression capacity than control after both screening protocols.

Note: *These were Phase 1 screening exposures, not a substitute for extended qualification testing. The project roadmap specifically calls for expanded freeze–thaw, wet–dry, UV, and weathering evaluation.*

Applications, Economics & Commercialization

Commercial development is focused on two product families where recovered mattress foam and textile fibers provide clear functional value and can absorb meaningful material volume.

Commercial pathway	Why the recovered materials fit	Representative applications
Acoustic panels / sound barriers	Sound attenuation; lower density; complex printed geometry; potential foam-filled cavities	Architectural acoustic panels, partitions, sound barriers
Prefabricated non-structural components	Design-flexible products using recycled foam for lightweighting and textile fibers for reinforcement.	Benches, planters, architectural panels, site furnishings







Representative design directions and printed prototypes shown in the Phase 1 source report.

Processing economics

Modeled large foam fraction handling at approximately $0.15/kg, refined 1–5 mm foam at approximately $0.53/kg, chopped textile fiber at approximately $0.25/kg, and micronized foam at approximately $353/kg.

Route	Target size	Modeled cost	Role
Large foam fraction	1–2 in	~$0.10/kg	Acoustic / cavity fill
Refined foam for printing	1–5 mm	~$0.53/kg	Printable cementitious mixes
Chopped textile fiber	~12 mm	~$0.25/kg	Reinforcement
Micronized foam	100 microns	$353/kg	Fine particle packing

Commercial implication. *The commercial model assumes approximately: 150 kg/h foam-processing throughput, 300 kg/h textile-processing throughput, & labor, electricity, maintenance, equipment amortization, mineralization / packing, and handling allowances.*

Estimated Cost Impact on Representative Products

These values represent the cost contribution of the recycled foam and textile only; they do not include cement, sand, admixtures, printing labor, finishing, freight, overhead, or margin.

Product example	Assumed size / volume	Foam addition *(1-5 mm)*	Textile addition	Incremental recycled-material cost
Acoustic panel	600 × 600 × 50 mm - 0.018 m^3	~0.24 kg / **~$0.13**	~0.11 kg - ~$0.03	~$0.16 per panel
Decorative planter	Ø 400 × 300 mm - 0.038 m^3	~0.51 kg / **~$0.27**	~0.23 kg - ~$0.06	~$0.33 per planter
Bench	1500 × 400 × 450 mm - 0.27 m^3	~3.64 kg / **~$1.93**	~1.62 kg - ~$0.41	~$2.34 per bench

Product-level cost will be validated in Phase 2 using measured deposited volume, material consumption, and foam-fraction split.

Phase 2 Roadmap

Phase 1 substantially de-risked the material system and established the processing, performance, and manufacturing foundation for scale-up. The next phase is intended to move from controlled development work toward pilot-ready manufacturing and commercialization.

Workstream	Phase 2 focus
Scale formulation	Larger batches; mix refinement; recycled-content optimization; process consistency and batch reproducibility.
Foam-fraction validation	Compare 1–5 mm-only foam with the tested shredded + micronized hybrid to determine the minimum processing required for acceptable printability and performance
Validate durability	Extended freeze–thaw and wet–dry exposure; UV / weathering evaluation; confirmation of outdoor suitability.
Pilot AM demonstrations	Full-scale additive-manufacturing trials; acoustic-panel prototype; architectural / site-furnishing prototype; throughput analysis.
Commercial readiness	Techno-economic model; cost per unit and scale-up plan; commercialization pathway; pilot preparation and market deployment.

Pilot-scale printing	Extended performance & durability data	Representative product prototypes	Verified product-level economics	Commercial scale-up roadmap

Phase 1 conclusions

- *Recovered mattress polyurethane foam and textile fibers can be processed into controlled feedstocks for cementitious-composite development.*
- *The tested hybrid fine-foam formulation—5 g 1–5 mm shredded foam plus 5 g micronized foam—demonstrated a viable direct-printing pathway while maintaining approximately control-level 28-day mechanical performance and lowering specimen density.*
- *Textile fiber provided a distinct reinforcement pathway, with the 28-day fiber formulation achieving +52.4% compression, +42.7% flexural strength, and +45.5% splitting tensile strength relative to control.*
- *The combined foam + textile formulation achieved +47.2% 28-day compressive strength with 7.4% lower specimen weight and the highest calculated specific compressive strength, 19.62 MPa·cc/g.*
- *Larger foam chunks demonstrated a promising secondary pathway for hollow-core and acoustic applications, averaging 12.65 dB below control across the six measured frequencies in Phase 1 screening.*
- *Bench-scale printability was demonstrated across all four formulations; the fiber formulation's 7.5% bead-width CV was slightly above the ≤7% dimensional-consistency target and should be refined in Phase 2.*
- *The updated scale-processing model projects approximately $0.53/kg for 3–5 mm foam and $0.25/kg for ~12 mm textile under higher-throughput assumptions.*
- *Phase 2 should validate fraction-specific bulk densities, actual batch yield, 1–5 mm-only versus hybrid foam formulations, extended durability, standardized acoustic performance, pilot-scale additive manufacturing, and product-level economics.*
- *The strongest near-term commercialization pathways remain acoustic panels / sound barriers and prefabricated non-structural architectural components.*

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Appendix - Material accounting basis

The phase 1 material accounting is based on the following:

1. **Design sand removal.** The formulation reduced sand from 2,500 g to 2,000 g. Using a density of 2.70 g/cm^3 for sand, that is a valid **20.0 vol% design reduction in the original sand volume**.
2. **Foam loading basis.** The tested formulation contained **10 g of total polyurethane (PU) foam per batch**, consisting of **5 g of mechanically shredded 1–5 mm mattress PU foam** and **5 g of RoCo micronized PU foam**. This hybrid particle-size distribution was selected to improve packing efficiency: the micronized fraction can occupy void space between the larger shredded particles, while the 1–5 mm fraction provides greater lightweighting and contributes to acoustic porosity.
    a. Using the project working density bases:
        i. **1-5 mm shredded PU foam:** 5 g at 64 kg/m^3 = **78.1 cm^3**
        ii. **RoCo micronized PU foam:** 5 g at 140–175 kg/m^3 = **28.6–35.7 cm^3**
    b. The resulting **total occupied foam volume is approximately 106.7–113.8 cm^3 per batch**. Relative to the original sand-volume basis, this represents approximately **11.5 – 12.3 vol% foam**.
3. **Textile loading basis - how the ~5 vol% was reached.** The tested textile dose was **20 g/batch of ~12 mm chopped fiber.** The **"~5 vol%"** label refers to a **loose-bulk occupied-volume dosing basis,** not a true-solid material volume. Using the historical project characterization of about **7 lb/ft^3 (≈112.1 kg/m^3 = 0.1121 g/cm^3), giving 20 g ≈ 178.4 cm^3.** If that occupied volume is **5% of the batch,** the corresponding batch volume is about **3.57 L.** On a separate true-solid basis using **SG ≈ 1.2,** the same 20 g equals about **16.7 cm^3,** or about **0.9 vol% of dry-constituent absolute volume.** These two numbers are not contradictory - they describe different physical quantities.