Acoustic Performance of Rigid and Flexible Polyurethane Foams (PU) Using Functional Powder Additives

Executive Summary

In this study, we took post-consumer flexible PU foam, processed it through our proprietary mechanochemical shear-grinding process, and produced a functional powder with 100-to-200-micron size. We then incorporated that powder as an additive into both rigid and flexible PU foam systems and measured the acoustic performance. This white paper shares those results.

- **Problem:** Noise, Vibration, and Harshness (NVH) control is critical across construction, industrial, and consumer product applications; frequency shaping is often as important as peak sound level reduction.
- **Rigid foam (impact testing):** A standard rigid PU foam with just 10% powder addition reduces impact noise intensity by ~4 dB and shifts dominant frequency from 1,837 Hz to 985 Hz — a dramatic reduction in perceived harshness.
- **Flexible foam (sweep attenuation):** Powder-modified flexible PU foam demonstrates 15–35 dB broadband insertion loss across 1,500–2,500 Hz — the frequency range most critical to human hearing comfort.
- **Cost advantage:** Functional PU foam feedstock is reintroduced into the final product as a functionalized powder additive.

Technology & Materials (in Brief)

PU foam chunks are loaded into a proprietary mechanical grinder where, during the grinding process, the foam is perfused with pressurized gas (CO_2 or N_2). This gas perfusion imparts surface functionalization to each particle. Output: a free-flowing functional powder at 167–176 μm, bulk density ~0.140–0.175 g/cc, issued with a full batch Certificate of Analysis (CoA).

The powder is added volumetrically to the polyol component before standard two-part mixing, no specialized equipment or modified chemistry required. This drop-in approach is compatible with both rigid and flexible PU foam systems, requiring no modification to existing manufacturing lines.

Why Sound Dampening Occurs

In both rigid and flexible PU foam systems, dispersing powder particles creates micro-interfaces between materials of differing mechanical stiffness. For impact noise, energy arriving at these boundaries is reflected, absorbed through viscous friction within the particles' micro-pores, and converted to heat rather than transmitted (reducing intensity and shifting dominant frequency downward). For broadband transmission loss, the same impedance mismatch forces acoustic waves to scatter and attenuate across a wide frequency range rather than passing through the material. Human hearing is most sensitive to sharp transients above 1,500 Hz; moving impact energy below 1,000 Hz produces a sound perceived as noticeably less harsh and fatiguing, even before any dB reduction is considered.

Experimental Procedure

Impact testing (rigid PU foam): Steel ball bearing dropped from a fixed height through a PVC guide tube with alignment collar onto rigid foam samples in a calibrated acoustic enclosure. Sound intensity (dB) and dominant frequency (Hz) recorded per trial (ref. ASTM E989).

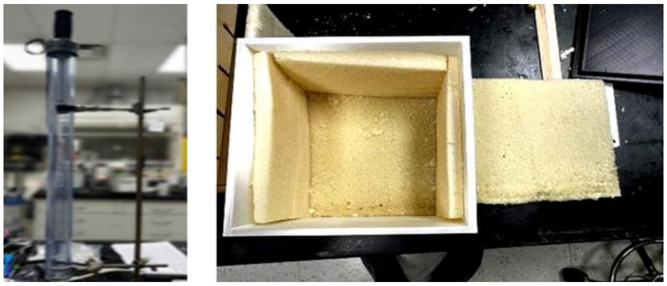

Figure 1 — Left: Ball-drop impact rig for rigid foam testing (ASTM E989). Right: Isolation box (speaker/mic slot) for controlled sweeps.

Sweep attenuation testing (flexible PU foam): Speaker and microphone placed in separate insulated enclosures with the flexible foam sample sandwiched between. Pure tones at 500–2,500 Hz played in sequence; insertion loss — the reduction in received sound level relative to no foam — calculated per frequency band.

Acoustic Performance: Attenuation and Modulation

Rigid foam - ball bearing impact test: A standard rigid foam with 10% powder addition reduces impact noise by ~4 dB vs. an unmodified baseline PU foam. The powder also shapes impact frequency: unmodified foam produces a dominant frequency of **1,838 Hz**; 5% loading shifts this to **985 Hz** (−853 Hz); 10% loading gives **1,953 Hz**.

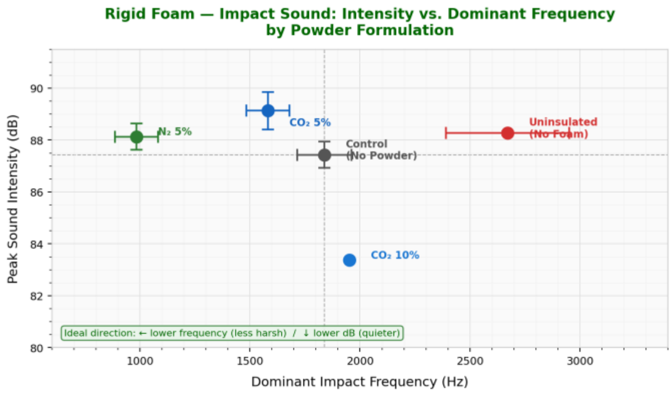

Figure 2 — Rigid foam impact results: peak sound intensity (dB) vs. dominant frequency (Hz) by formulation.

Flexible foam: Powder-modified flexible foam consistently achieved 15–35 dB insertion loss (IL) across 1,500–2,500 Hz. The top-performing formulation delivered a mean insertion loss of 24.4 dB across all tested frequencies. Together, these results demonstrate the powder additive's effectiveness across both rigid and flexible foam formulations.

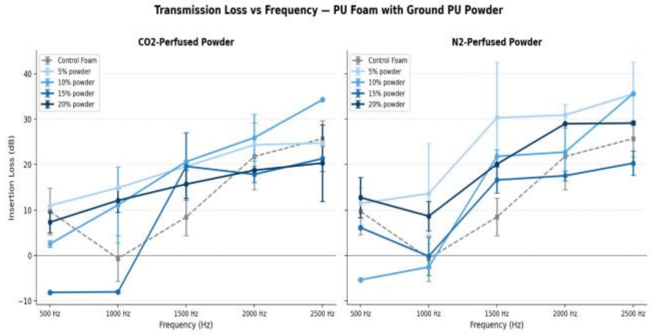

Figure 3 - Flexible foam transmission loss vs. frequency. All formulations show 15–35 dB insertion loss at 1,500–2,500 Hz.

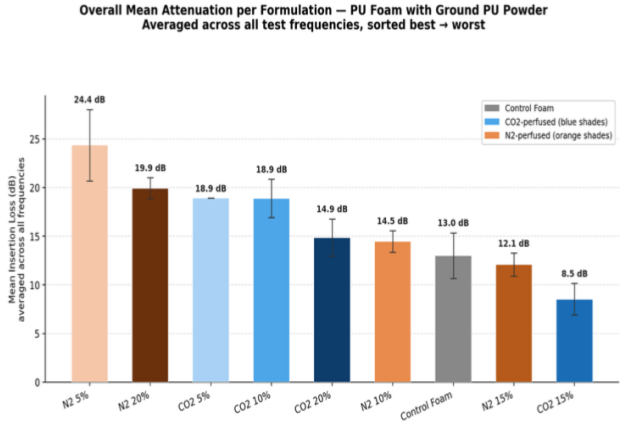

Figure 4 - Mean insertion loss ranked best to worst (bottom).

Key Results for OEM

- Frequency tuning and human comfort: 5% powder loading shifts dominant impact frequency from 1,837 Hz to 985 Hz (−852 Hz). Below 1,000 Hz, impact noise is perceived as far less harsh and fatiguing. The human ear is highly sensitive to sharp transients above 1,500 Hz. Varying powder % lets manufacturers tune to any specific NVH target.
- Attenuation - rigid foam: standard PU foam + 10% powder delivers ~4 dB impact noise reduction.
- Attenuation - flexible foam: 15–35 dB broadband insertion loss at 1,500–2,500 Hz; best formulation achieves 24.4 dB mean.
- Sustainability & cost: 100% recycled PU feedstock (~0.15 kWh/kg production energy) supports Scope 3 and circular economy targets and can be reintroduced into the final product with real sound modulation benefits.

OEM Integration & Readiness

Drop-in ready today. Add powder at the desired loading % to the polyol, mix as normal (with powder additive), cast as normal. No chemistry changes, no capital equipment, no reformulation required. Compatible with rigid and flexible foam applications including acoustic panels, wall insulation, industrial equipment enclosures, flooring underlays, and packaging.

The use of recycled feedstock directly lowers input material cost compared to virgin polyol, meaning acoustic performance and cost reduction are achieved simultaneously.

Sustainability, Limitations & Next Steps

- **Sustainability**: Low-energy production (~0.15 kWh/kg), negligible gate-to-gate impact vs. virgin polyol processes; strong circularity credentials for sustainability-led procurement.
- **Limitation:** Technology is at R&D and small-scale stage. The primary constraint is scale; commercial production volume scaling is actively underway.
- **Next steps:** A-weighted sweeps, spectral centroid, decay constants; OEM pilot integration.

Quick Reference

Impact results from rigid foam testing; sweep attenuation from flexible foam testing. Lower frequency = softer, less harsh sound. Negative Δ dB = quieter. Adjust powder % to hit your NVH target.

Rigid Foam — Impact Testing			
Additive	**Dom. Freq.**	**Δ Freq.**	**Δ dB — Key Benefit**
Baseline	1,838 Hz	—	Reference — sharp, high-pitched transient
5% Powder	985 Hz	−853 Hz	+0.7 dB — pitch drops 47%; much less fatiguing
10% Powder	1,953 Hz	+115 Hz	−4.1 dB — strongest intensity reduction
Flexible Foam — Sweep Attenuation (Mean IL)			
Best (N2 5%)	24.4 dB	35.5 dB peak	Highest mean IL across all frequencies tested
10% Powder avg.	18.9 dB	34.3 dB peak	Strong broadband attenuation at 1,500–2,500 Hz
All formulations	15–35 dB	at 1,500–2,500 Hz	Consistent broadband benefit across all loadings