GREEN-LOOP

Greenloop bio-rubber value chain

External workshop - 16/07/2025

Funded by the European Union

This project has received funding from the European Union's Horizon Europe, grant number 101057765. UK Participants in Horizon Europe Project GREENLOOP are supported by the UK Research and Innovation (UKRI) under the UK government's Horizon Europe funding guarantee, grant number 10038028.

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Agenda

- Introduction to Greenloop (5 mins)
- Introduction to bio-rubber value chain (5 mins)
- Chemical devulcanisation and multilayered rubber results (10 mins)
- Vibration testing results (10 mins)
- Fire testing results (15 mins)
- Q&A (15 mins)

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Introduction

Tom Andrews, NCC

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GREEN-LOOP Overview

MISSION

Bio-rubber

Bio-plastic

Wood composite

APPROACH

Circular economy

Raw materials

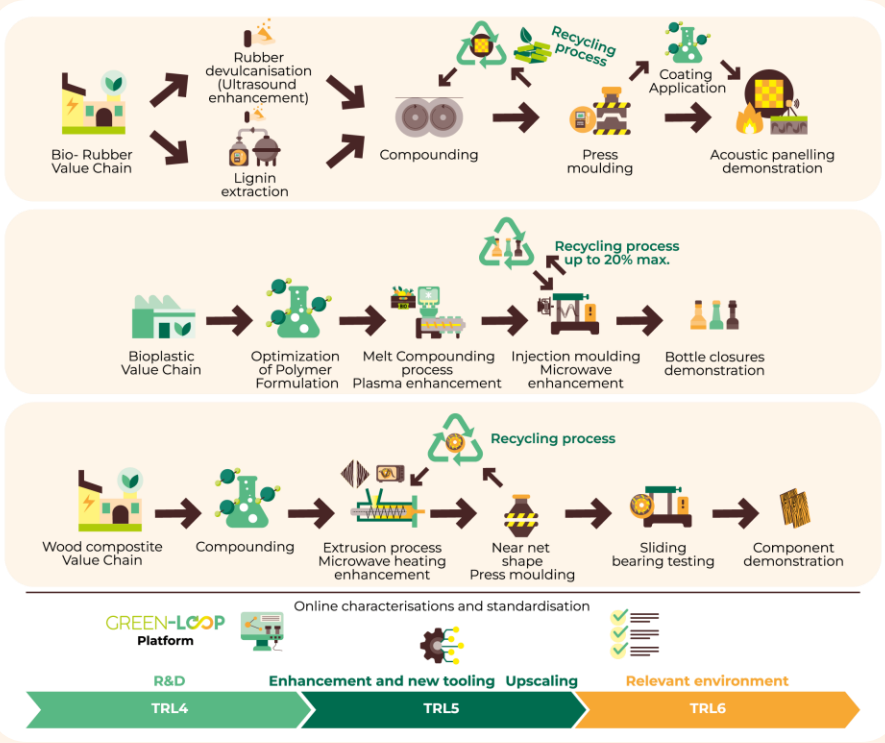
End-of-life

INNOVATION

AI-driven manufacture

Microwave-enhanced

Digital platform



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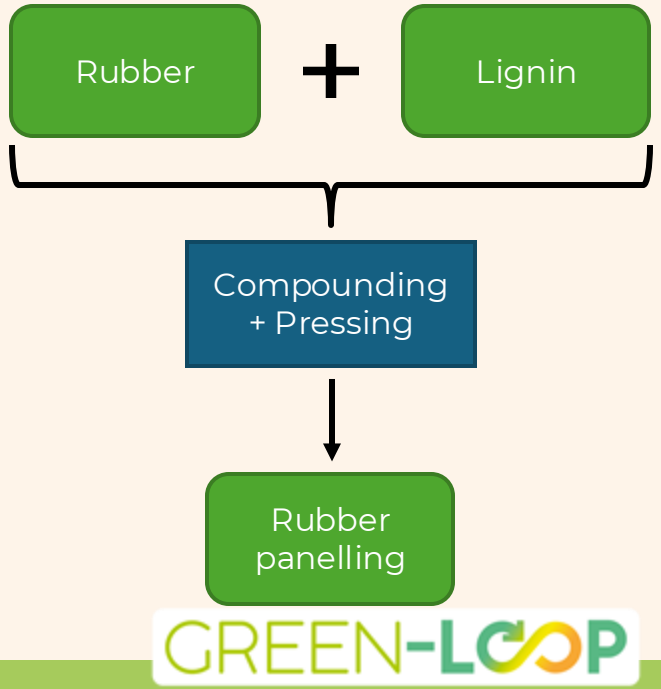
Introduction to bio-rubber value chain



Why target these materials?

Rubber: **3.2 million tonnes of used tyres** are generated annually in Europe → Acoustic dampener

Lignin: **950 million tons of biomass** produced annually in Europe → Flame retardant

How can their value be kept in a circular economy

What is the market gap?

Recycled rubber panels on the market but rubber mainly used as filler:

- bound with virgin fossil-derived resins
- hard to recycle

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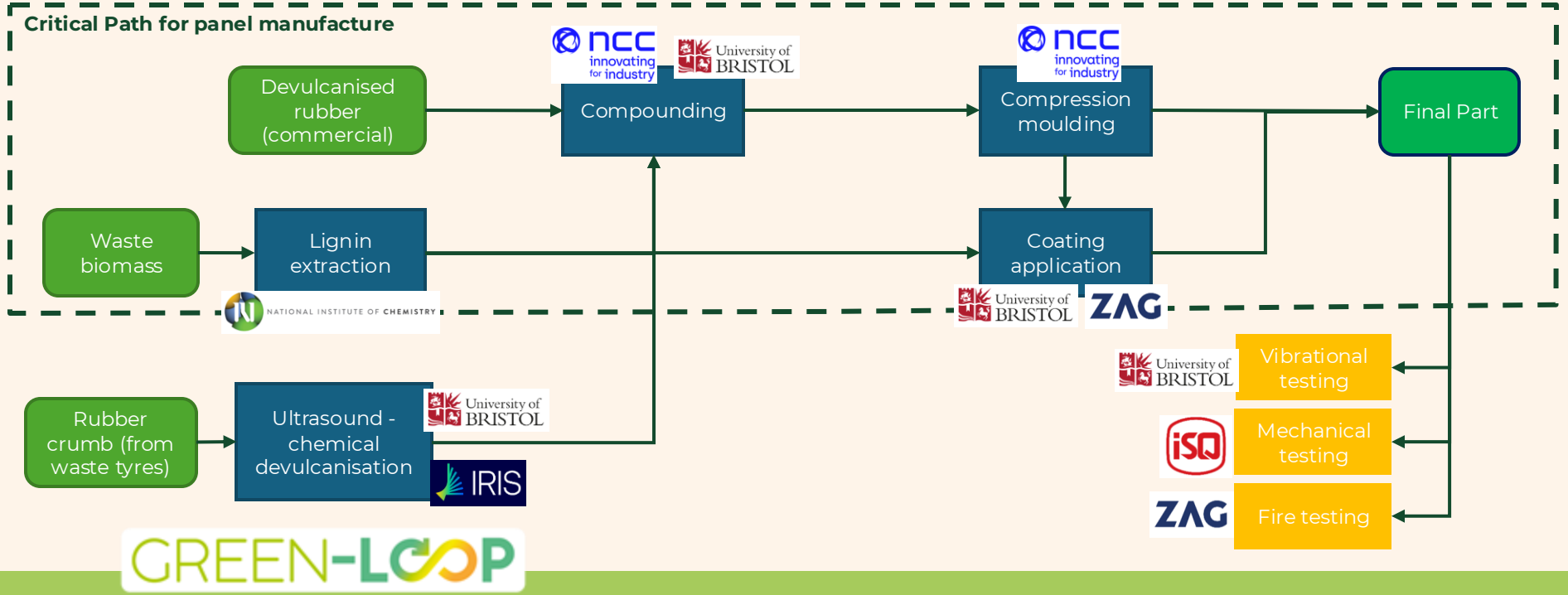

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Rubber devulcanisation results

Hesam Ramezani, University of Bristol

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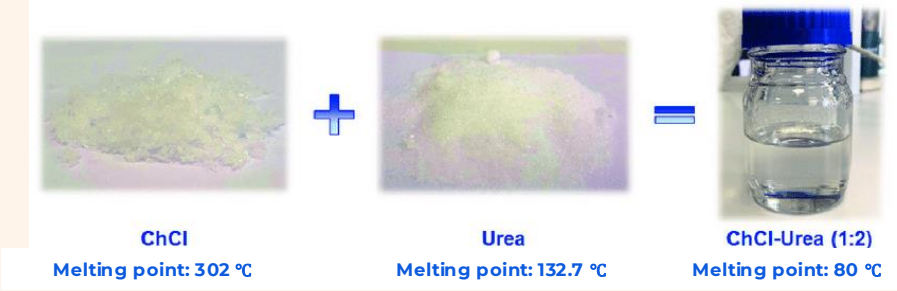
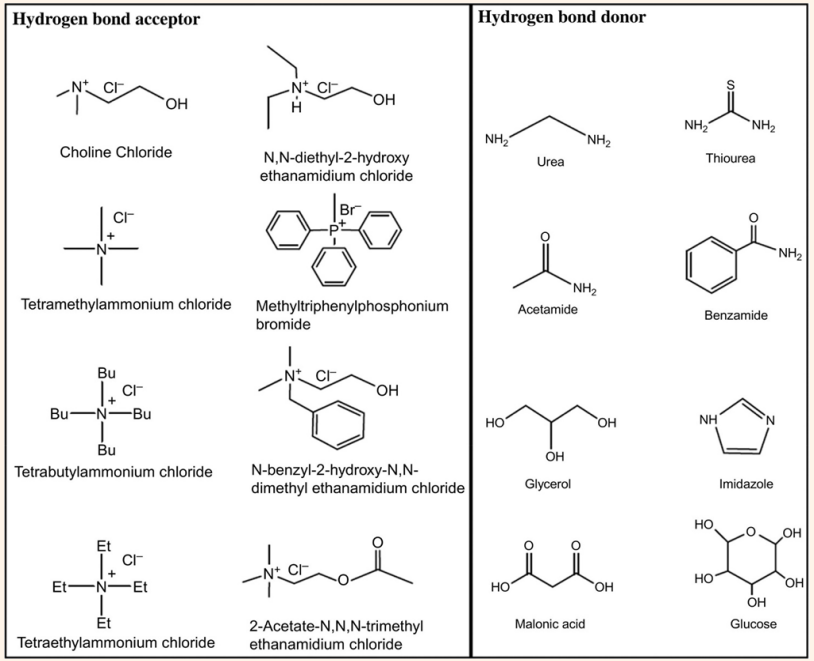
Devulcanisation using Deep Eutectic Solvents (DES)

- Combination of 2 or 3 components
- Capable of forming Hydrogen bonds
- Synthesised using a simple heater stirrer
- Low temperature





Ramezani, H., Scarpa, F., Zhang, Q., Ji, W., Khorramshokouh, A., Rochat, S., ... & Thakur, V. K. (2024). Green and sustainable devulcanization of ground tire rubber using choline chloride–urea deep eutectic solvent. *RSC Sustainability*, *2*(8), 2295-2311.

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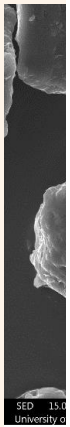
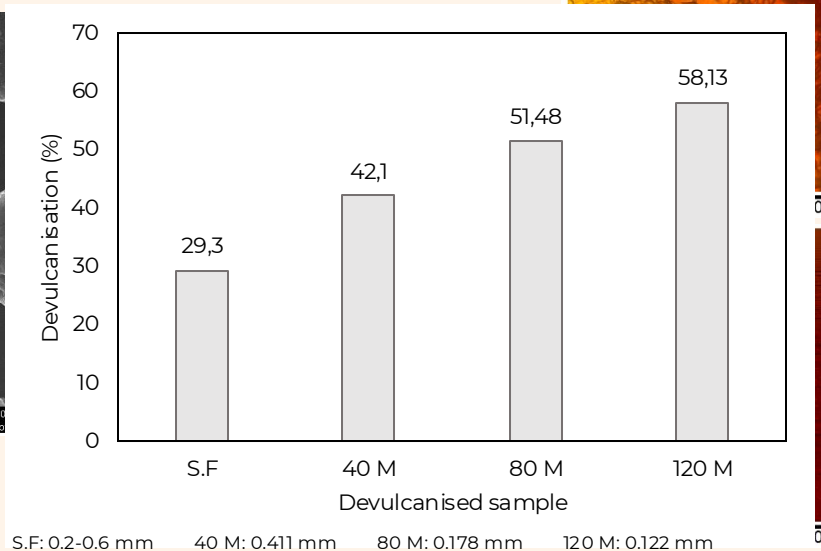
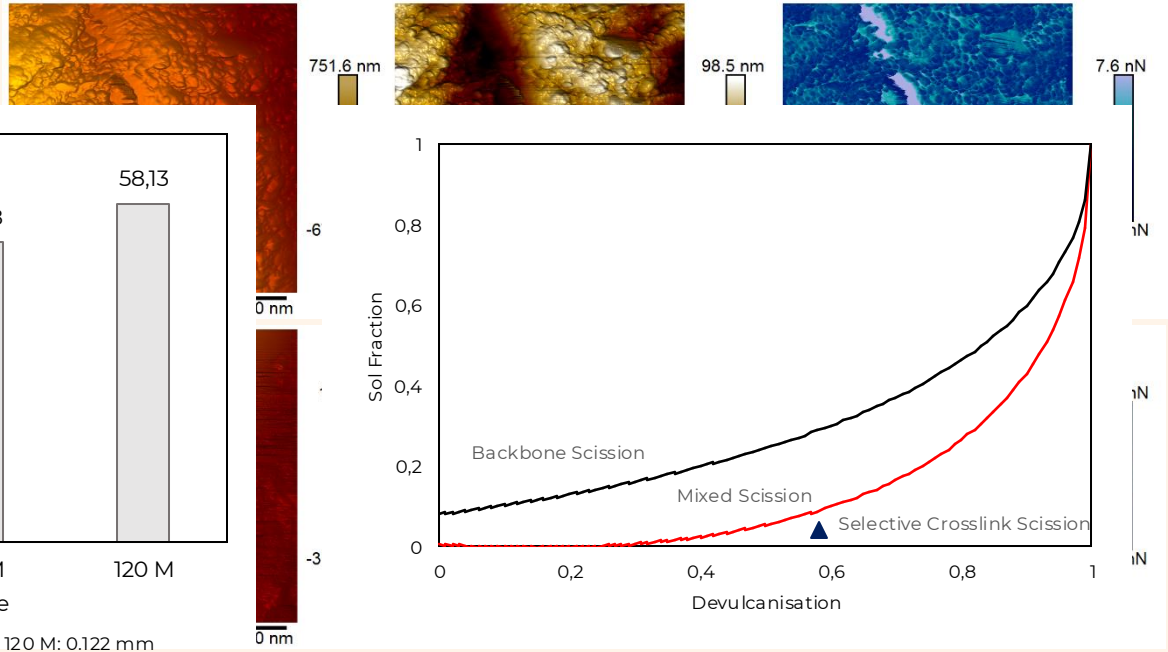
Devulcanisation of crumb tire rubber

Nearly 60% devulcanisation







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Multilayered rubber results

Hesam Ramezani, University of Bristol

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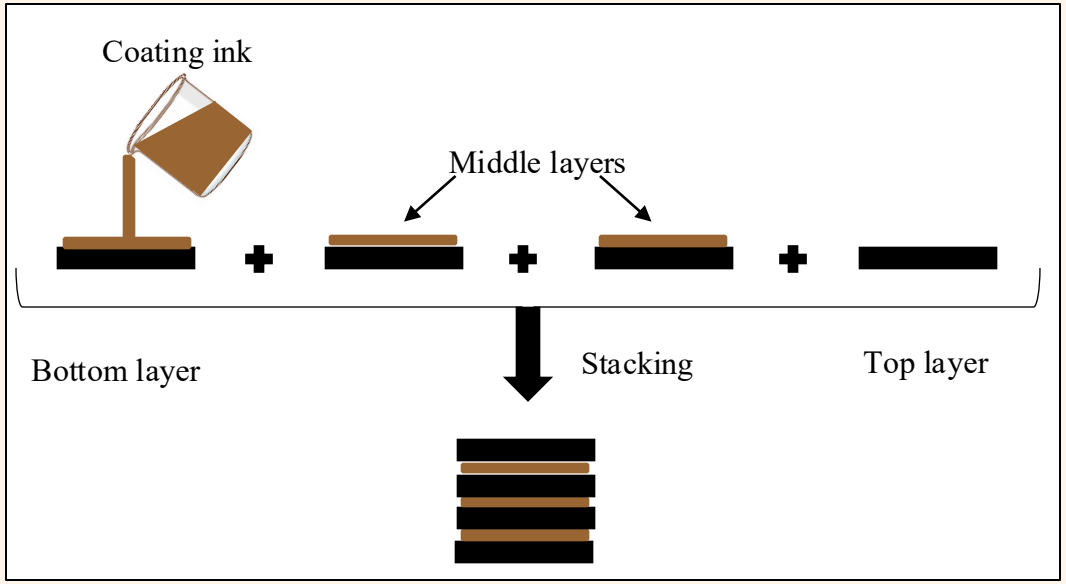
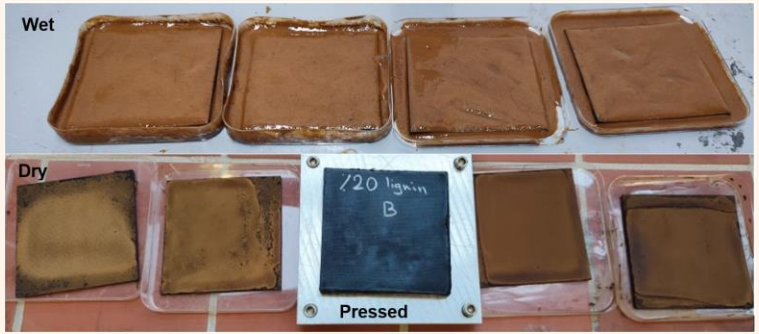
Coating ink and multilayered rubber





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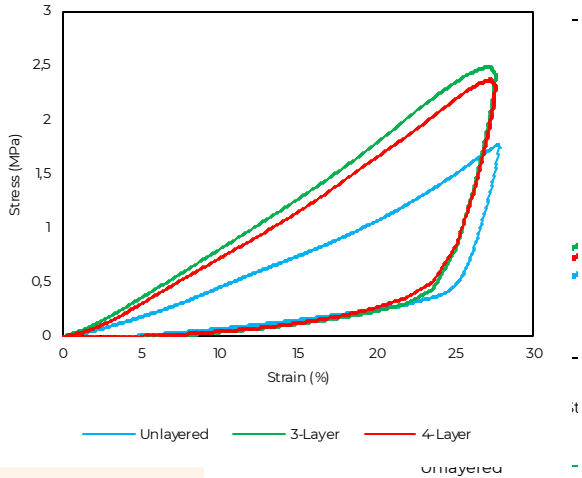
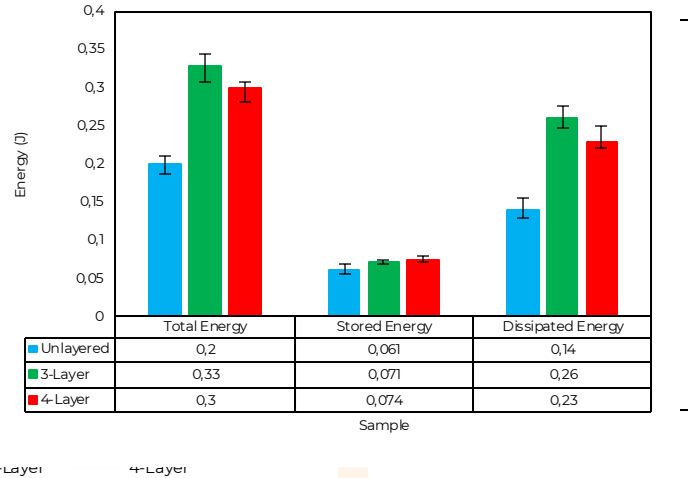
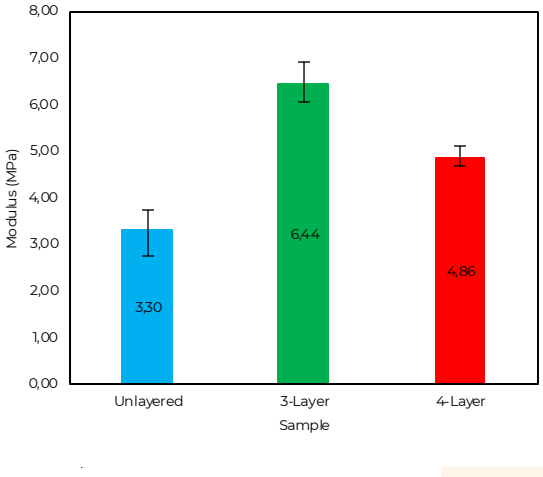
Monotonic and cyclic compression test results





	Total Energy	Stored Energy	Dissipated Energy
Unlayered	0,2	0,061	0,14
3-Layer	0,33	0,071	0,26
4-Layer	0,3	0,074	0,23



The coated multilayered rubbers possess enhanced damping performance and hysteresis compared to the unlayered samples

The coated multilayered rubbers exhibit improved compressional modulus and strength compared with the unlayered samples in the monotonic compression tests

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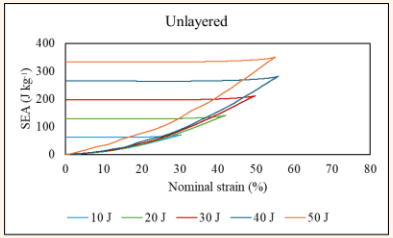
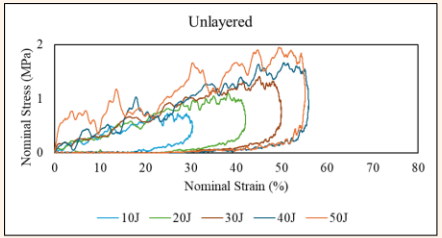
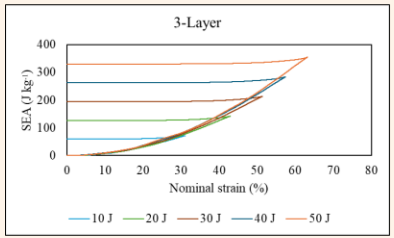
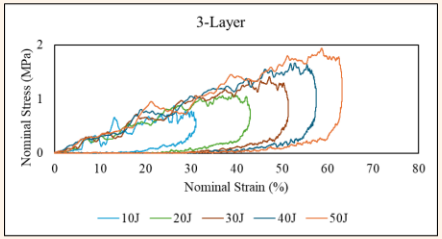
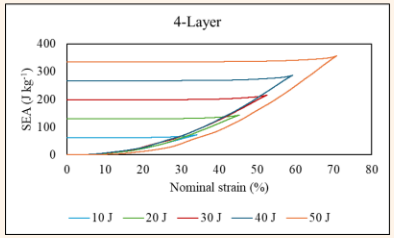
Impact and acoustic test results

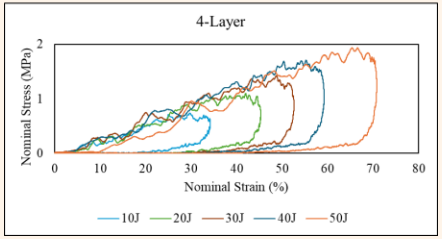




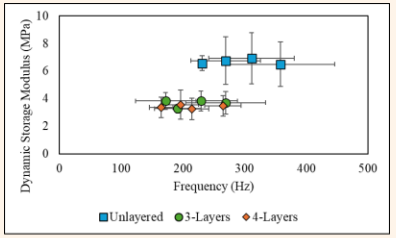


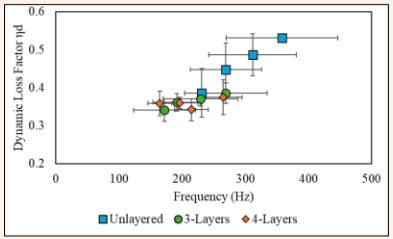




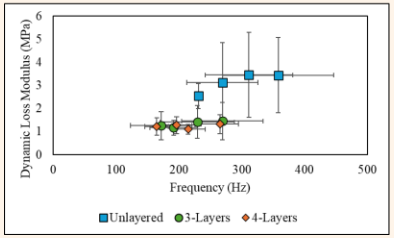


The specific energy absorption (SEA) is similar, but the nominal strain for the 4-layer samples is larger at maximum impact energy





The vibrational transmissibility performance of the unlayered samples is superior to that of the layered samples.



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Vibration testing

Fabrizio Scarpa, University of Bristol

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- Tests carried out using modular and flexible floor rig
- Two types of platform (stiff and flexible)
- Hammer and sine sweep tests (0.5 Hz – 30Hz)
- Concentrated masses for the equivalent of 75kg
- Sine sweep tests most statistically reliable – good comparison with hammer tests
- Walking tests (25 walks recorded, human of 70 kg + bag)
- Tests on 0wt% and 20wt% lignin panels

Stiff Platform

3m Span Length

Flexible Platform

5m Span Length

Distributed weight equivalent to tile weights

Tansu Gokce, Adam Crewe, Anastatios Sextos

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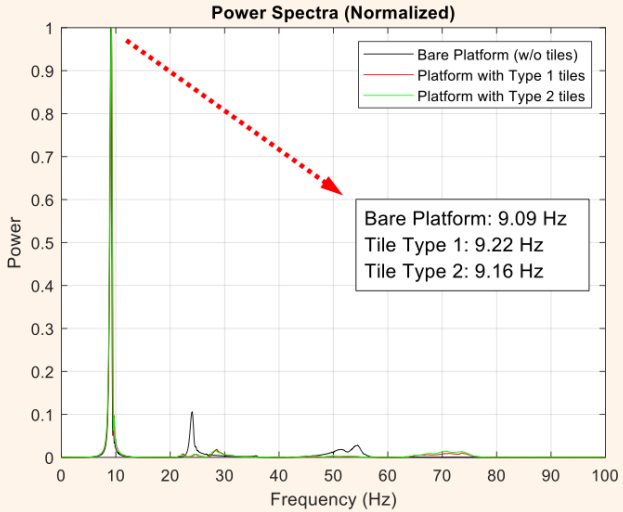
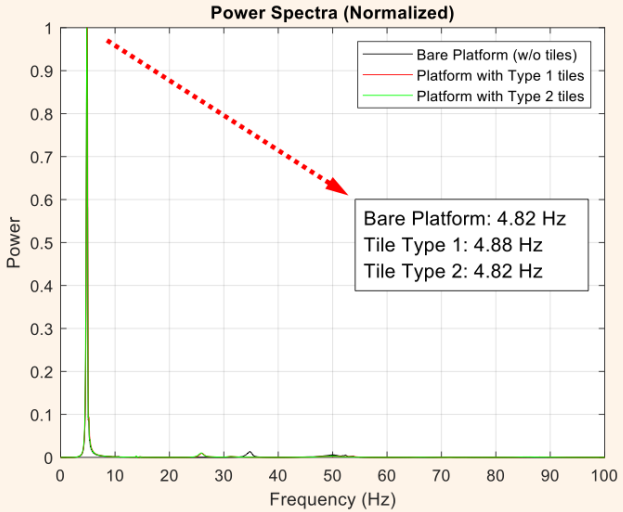
- Sine sweep
- A single pulse applied with an actuator and free vibration of the platform recorded
- Data filtered using a 3rd-order band-pass filter with a cutoff frequency of 0.5 Hz-20Hz

Stiff Platform
3m Span Length



Flexible Platform
5m Span Length



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Type 1 Tile = **0 wt% lignin**
Type 2 Tile = **20 wt% lignin**

	3m Span Length		5m Span Length	
	Freq. (Hz)	Damping (%)	Freq. (Hz)	Damping (%)
Bare System	9.09	1.45	4.88	1.85
Type 1 Tile	9.22	1.73	4.88	2.08
Type 2 Tile	9.16	1.78	4.82	2.07

↓ Increase in damping

	3m Span Length (with 75 kg)		5m Span Length (with 75 kg)	
	Freq. (Hz)	Damping (%)	Freq. (Hz)	Damping (%)
Bare System	5.65	1.44	2.81	2.2
Type 1 Tile	5.62	1.74	2.81	2.2
Type 2 Tile	5.55	1.72	2.81	2.23

↓ Increase in damping

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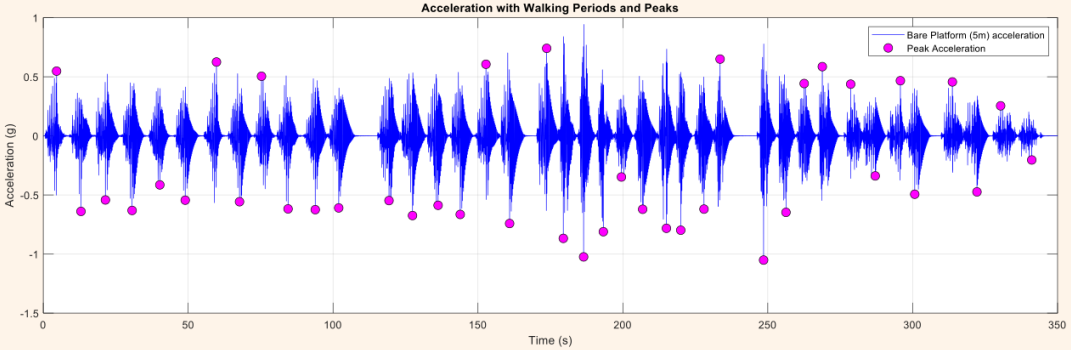
Large scale walking tests



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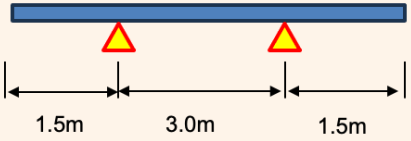
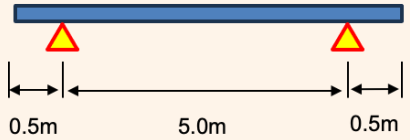
Stiff Platform (3m Span Length)



3m Span Length - Accelerations				
	Number of Walking Cycle	Peak Acceleration (g)	Std Dev. (g)	Attenuation (%)
Bare System	54	0.170	0.050	-
Type 1 Tile	61	0.167	0.045	2%
Type 2 Tile	60	0.165	0.053	3%

3m Span Length - Displacements				
	Number of Walking Cycle	Peak Displacement (mm)	Std Dev. (mm)	Attenuation (%)
Bare System	54	7.035	1.085	-
Type 1 Tile	61	6.988	1.085	1%
Type 2 Tile	60	6.366	1.000	10%

Flexible Platform (5m Span Length)



5m Span Length - Accelerations				
	Number of Walking Cycle	Peak Acceleration (g)	Std Dev (g)	Attenuation (%)
Bare System	40	0.595	0.176	-
Type 1 Tile	40	0.478	0.145	20%
Type 2 Tile	40	0.440	0.143	26%

5m Span Length - Displacements				
	Number of Walking Cycle	Peak Displacement (mm)	Std Dev. (mm)	Attenuation (%)
Bare System	40	35.884	4.257	-
Type 1 Tile	40	33.219	4.207	7%
Type 2 Tile	40	32.569	4.471	9%

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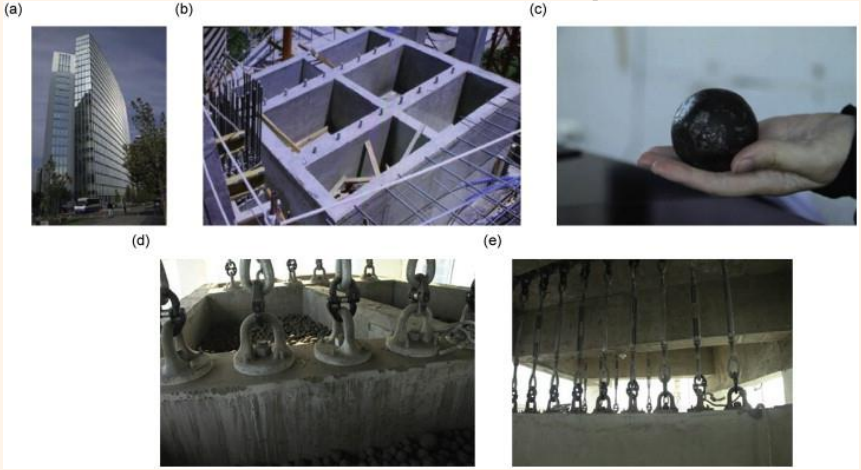
Particle dampers with recycled rubber



(https://doi.org/10.1016/j.jsv.2011.12.022)

- Passive damping device using the interaction of particles within a confined space to damp vibrations
- Used in civil constructions, turbine blades, rocket engine turbo-pumps and rotary printing equipment

Youbohong Kong

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$$x = X\sin(\omega t) \qquad \Gamma = X\omega^2/g$$

$$\epsilon\ominus_{\text{granular}} = 2\pi \mathrm{P}_{\text{dissipated}}/\omega\widetilde{\mathrm{E}}^{\max}_{\text{dissipated}}$$

$$\left(\mathrm{P}_{\text{dissipated}}\right)_{\text{experimental}} = \sum_{k=1}^{N-1} |\mathbf{F}_k||\mathbf{V}_k|\cos\left(\varphi_{\mathbf{F}_k} - \varphi_{\mathbf{V}_k}\right)/2$$

$$\widetilde{E}^{\max}_{\text{dissipated}} = 4(\Gamma g/\omega)^2 \sum_{i=1}^{N_{\text{particle}}} m_i$$

$$\tilde{\epsilon}_{granular} = \frac{\epsilon_{granular}}{\rho_f/\rho_g}$$

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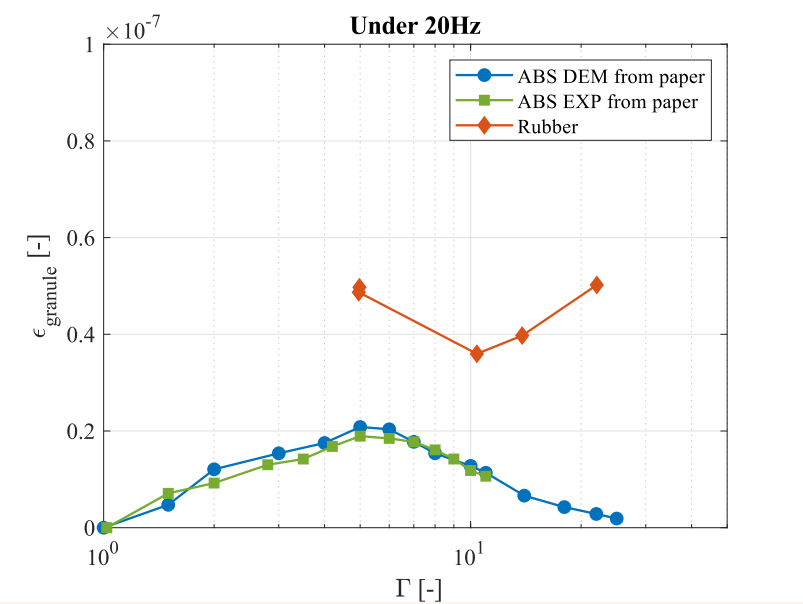

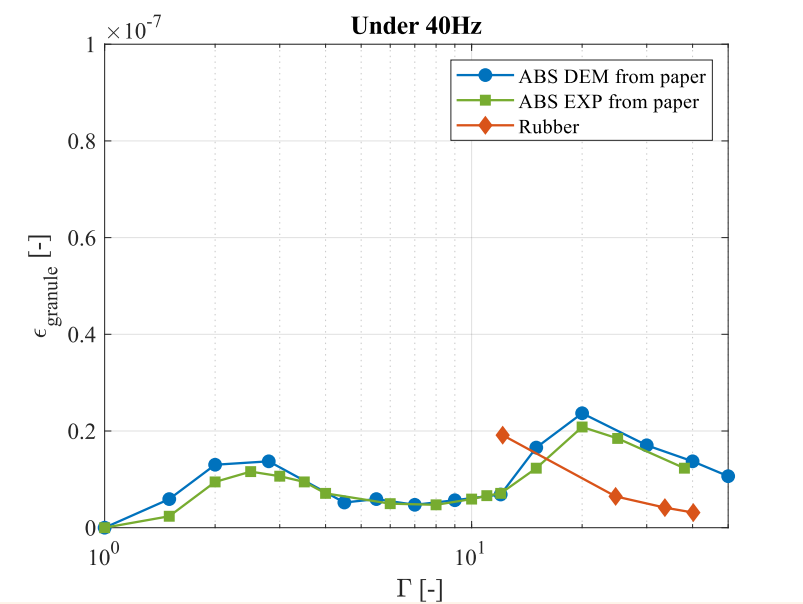

Increased energy dissipation efficiency at lower frequencies and high vibration amplitudes

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Reaction to fire results

Frederik Knez, Slovenian National Building And Civil Engineering Institute (ZAG)

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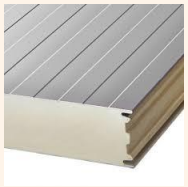
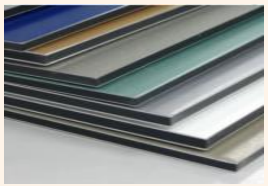
Reaction to fire (EN 13501-1)

Material/products of different reaction to fire class

A1 A2 — Non-combustible materials

B C — Hardly combustible materials





D — Normally flammable materials

E — other

Testing equivalent

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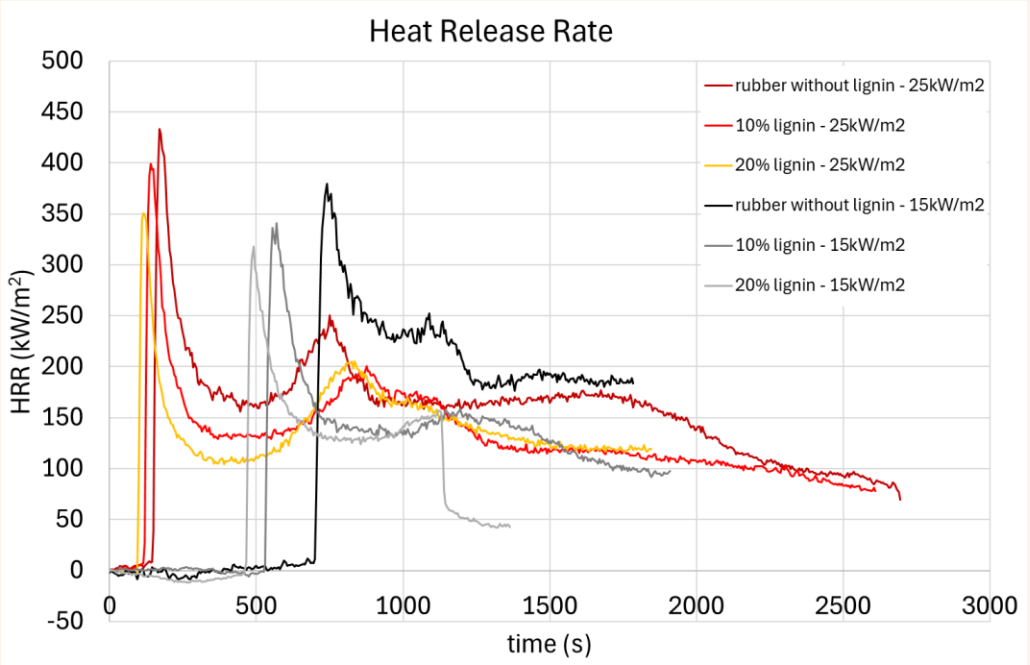
Cone calorimeter (ISO 5660-1) – 25 and 15 kW/m²

Heat release rate (HRR) for rubber without or with lignin (10% and 20% mixture) at two incident heat fluxes:

- 25 kW/m², 15 kW/m²
- No lignin, 10% and 20% of lignin
- More lignin – faster ignition, lower peak HRR
- Lower incident heat flux – significant ignition delay, a little lower HRR



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Small flame test (EN ISO 11925-2) – class E

30 s flame application		Ignition-when?	Max height of flame-when?	Flaming stopped-when?
rubber no lignin	surface	no		
	edge	yes (2 s)	100 mm (60 s)	No (> 60 s)
rubber 10% lignin	surface	no		
	edge	yes (2 s)	90 mm (60 s)	No (> 60 s)
rubber 20% lignin	surface	yes (25 s)	40 mm (30 s)	Yes (30 s)
	edge	yes (2 s)	100 mm (60 s)	No (> 60 s)

Class E requirements:

- 15 s pilot flame exposure
- Flame height during 20 s of testing time < 150 mm

Class D, C or B requirements: (together with SBI testing):

- 30 s pilot flame exposure
- Flame height during 60 s of testing time < 150 mm

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Single burning item (EN 13823)

Potential class D or higher

- For unprotected, exposed samples minimum class C is required
- Requires a lot of fire retardancy

The sample did not pass the test

- Class E is realistic for untreated material, requires either covering or additional surface treatment

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Floorings (EN ISO 9239-1)

The test method has similarly shown E_{fl} class

- Additional surface treatment is required to elevate class if needed
- A few variants have been considered

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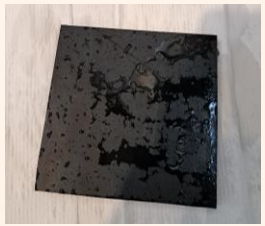
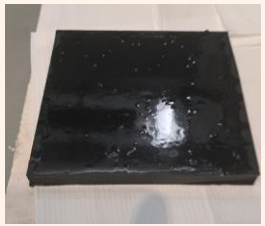
Additional treatment - description

Material surface was treated with

- Fire retardant in spray (for textile) → poor adhesion
- Sodium silicate (water glass)
- **Sodium silicate with 1% lignin mixture (saturated)**→ enhanced adhesion
- Sodium silicate with 0,5% lignin mixture





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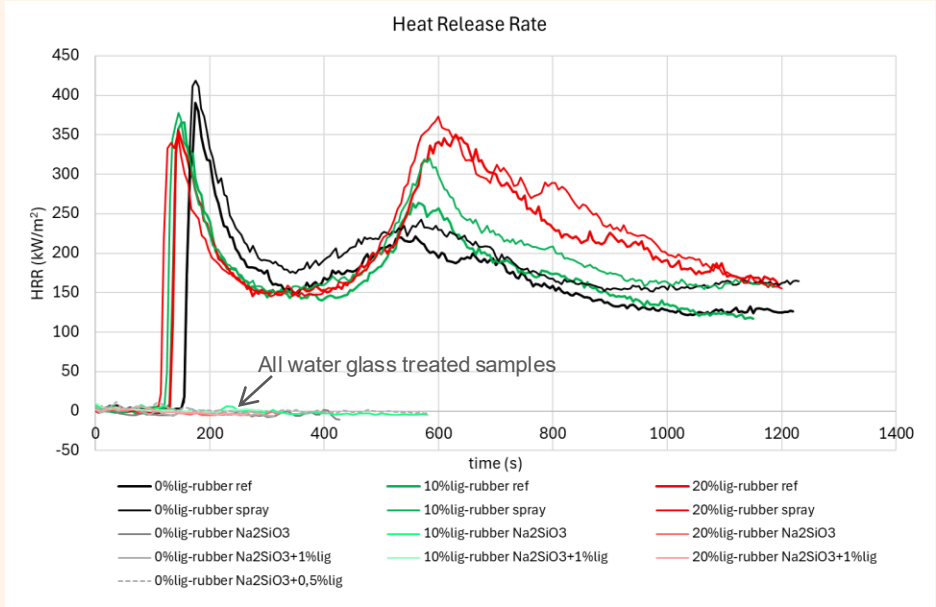
Additional treatment

- Non treated material and FR spray treated ignited.
- Sodium silicate treated surface (without or with added lignin) did not ignite.
- Sodium silicate with added lignin has better surface adhesion
- Rubber with added lignin:
  - ignited faster
  - Expands in volume during the test
  - Has lower first HRR peak
  - Has higher second HRR peak



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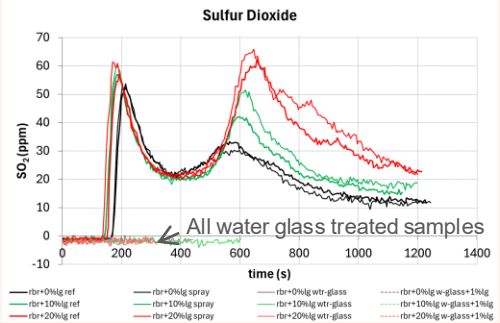
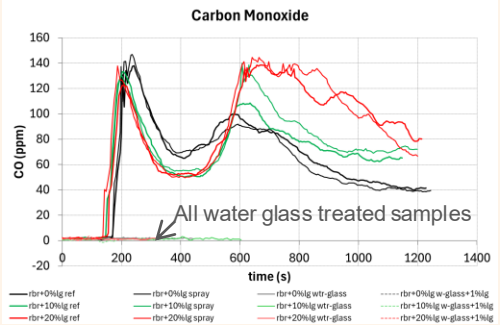
Smoke gases - FTIR

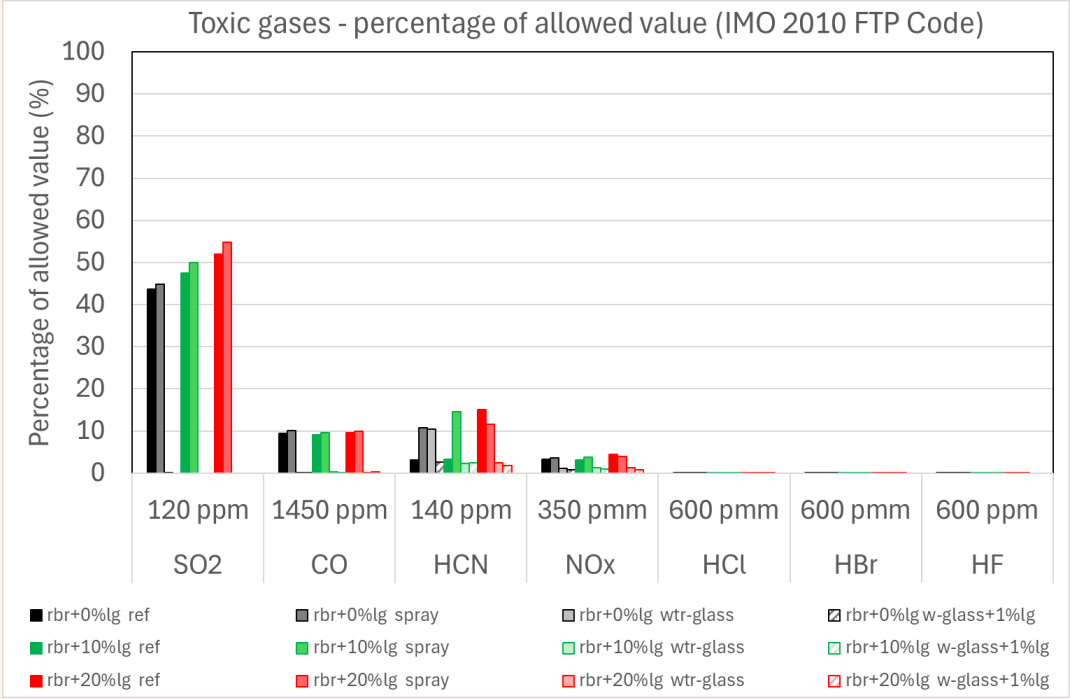
Limit values as given in IMO 2010 FTP Code

Values are conservative

SO2 < 120 ppm
CO < 1450 ppm
HCN < 140 ppm
NOx < 350 ppm
HCl < 600 ppm
HBr < 600 ppm
HF < 600 ppm







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Any questions?

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Thanks for listening

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