

# Novel composite materials from bulky wastes



Aleksander Hejna<sup>1,\*</sup>, Mateusz Barczewski<sup>1</sup>, Joanna Aniśko<sup>1</sup>,  
Jacek Andrzejewski<sup>1</sup>, Marek Szostak<sup>1</sup>, Adam Piasecki<sup>2</sup>, Roman  
Barczewski<sup>3</sup>, Paulina Kosmela<sup>4</sup>

[aleksander.hejna@put.poznan.pl](mailto:aleksander.hejna@put.poznan.pl)

<sup>1</sup> Poznan University of Technology, Institute of Materials Technology

<sup>2</sup> Poznan University of Technology, Institute of Materials Engineering

<sup>3</sup> Poznan University of Technology, Institute of Applied Mechanics

<sup>4</sup> Gdansk University of Technology, Faculty of Chemistry, Department of Polymer Technology



# Novel composite materials from bulky wastes



**INNOGOW - Supporting innovation in bulky waste management**

(Science for the Society II, NdS-II/SP/0039/2024/01)



**POLITECHNIKA  
BYDGOSKA**  
im. Jana i Jędrzeja Śniadeckich

Principal Investigator: dr inż. Aleksander Hejna

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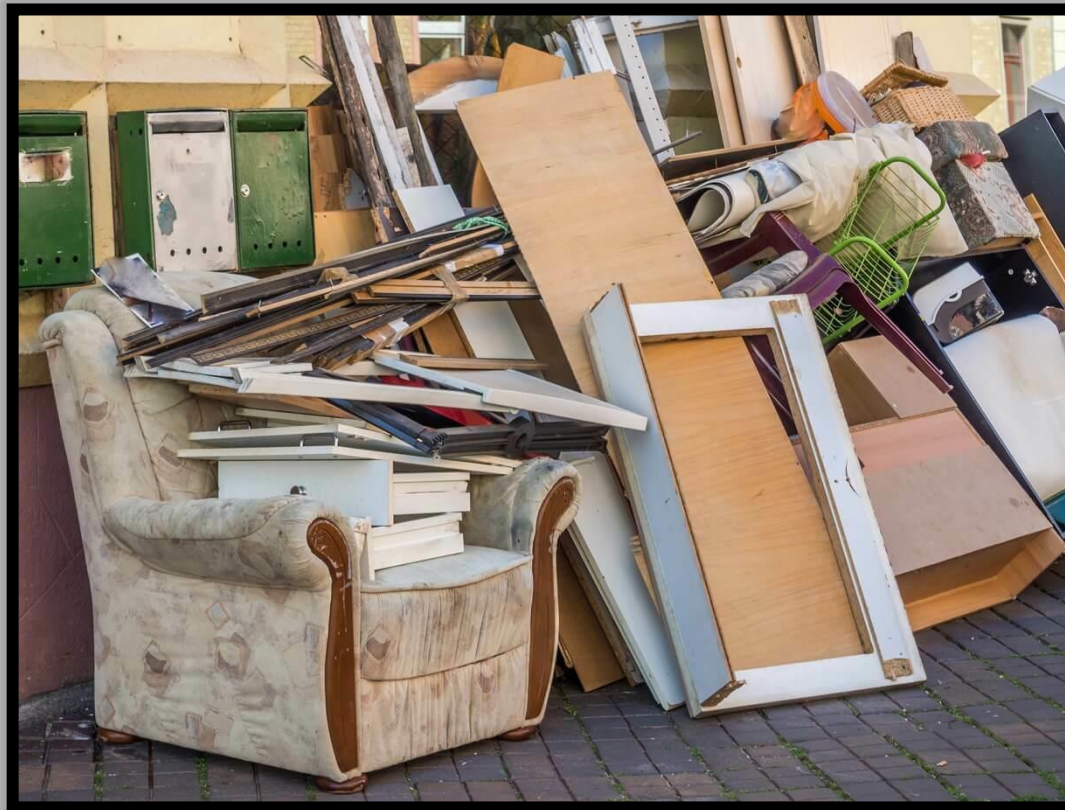
Implementation period: 07.02.2024 – 06.02.2027





## Bulky wastes

### Basic information

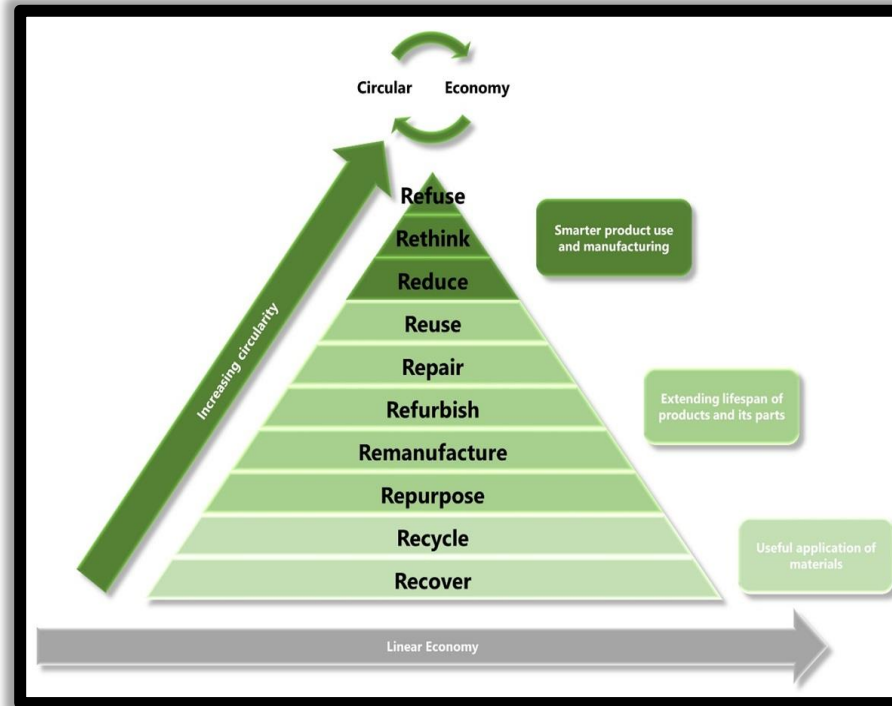
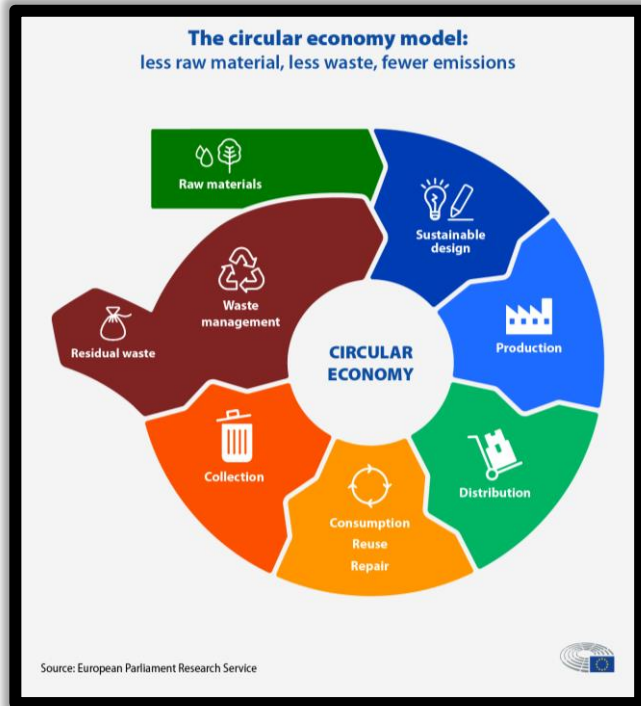


- Municipal waste generation in Poland (in million tons):  
10.9 (2015) → 13.7 (2021)
- Only 40% of recycling level
- Bulky waste – mainly wood, wood-based materials, and polyurethane foams
- Lack of efficient management methods and proper applications



# Circular Economy

## Motivation and measures



- EU Directives (Green Deal, Climate Target Plan)
- Penalties for not meeting targets
- Growing environmental awareness
- Need for novel waste management methods
- Need for final applications
- Need for high quality products





## Wastes

### Flexible polyurethane foams (PUFs)

From industrial PU systems, size below 2.8 mm

### Medium-density fiberboards (MDFs)

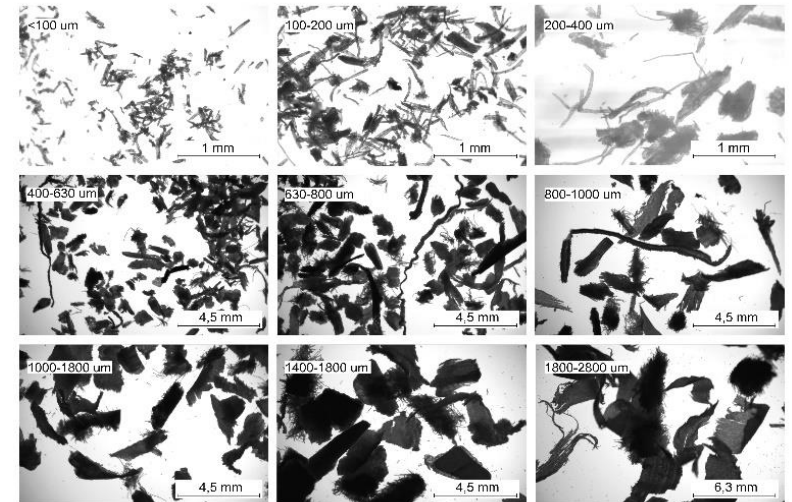
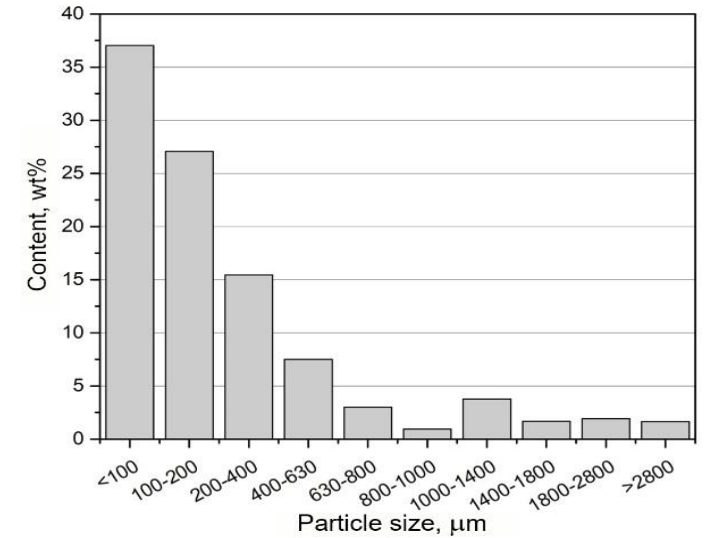
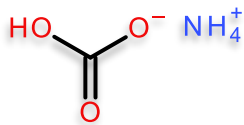
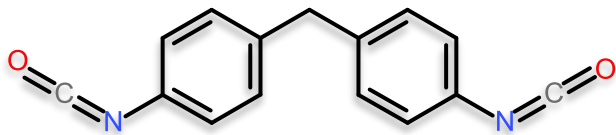
Waste from industrial production



## Binder

### Methylene diphenyl diisocyanate (MDI)

### Ammonium bicarbonate (AB)





## Applied compositions

Sample	Content, wt%			Binder composition, MDI:AB molar ratio	Molding temperature, °C	Molding time, min
	PUF	MDF	Binder			
1	90	0	10	1:0	160	5
2	67.5	22.5	10	1:0	160	5
3	45	45	10	1:0	160	5
4	22.5	67.5	10	1:0	160	5
5	47.5	47.5	5	1:0	160	5
6	42.5	42.5	15	1:0	160	5
7	45	45	10	3:1	160	5
8	45	45	10	2:1	160	5
9	45	45	10	1:1	160	5
10	45	45	10	1:2	160	5
11	45	45	10	1:3	160	5
12	45	45	10	1:1	120	5
13	45	45	10	1:1	140	5
14	45	45	10	1:1	180	5
15	45	45	10	1:1	200	5
16	45	45	10	1:1	160	1
17	45	45	10	1:1	160	2.5
18	45	45	10	1:1	160	10
19	45	45	10	1:1	160	15

## Composites preparation

**Cumulative content of waste: 85-95 wt%**

### Sample preparation

#### Pre-mixing:

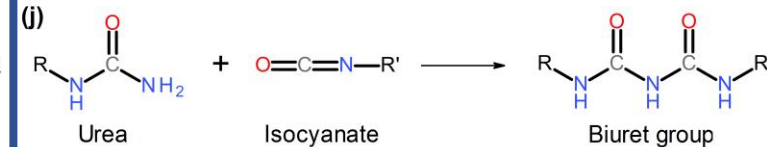
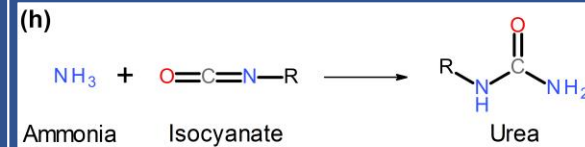
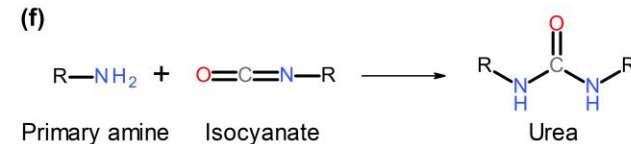
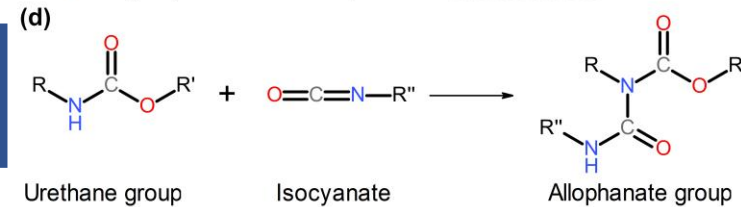
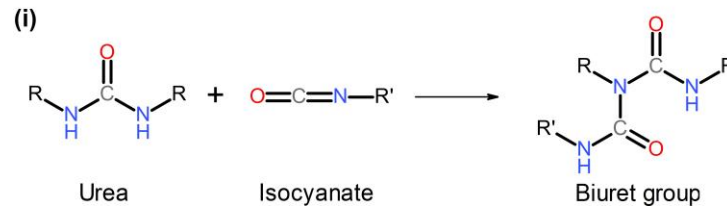
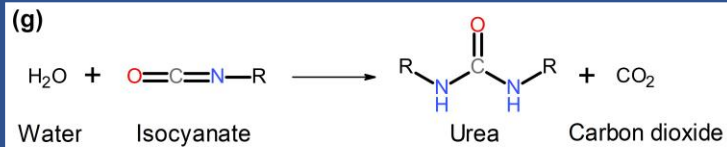
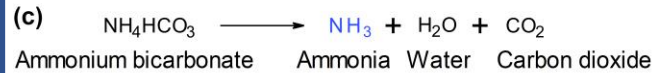
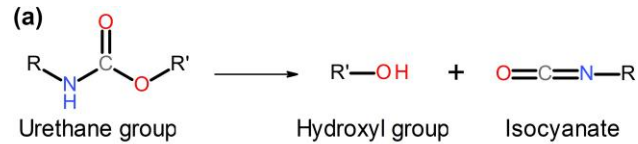
planetary mixer Gerlach GL 4219 (Germany),  
3 minutes, ambient temperature

#### Compression molding:

Fontjine LabManual 300 (Netherlands),  
1-10 minutes, 120-200 °C, 20 bar



## Chemical rationale for the applied binder compositions

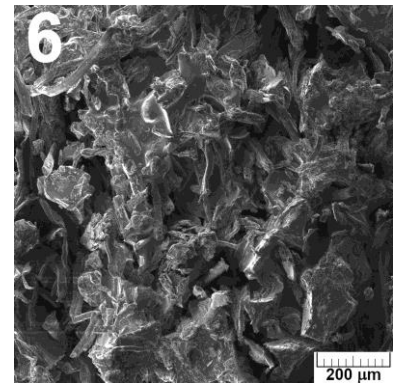
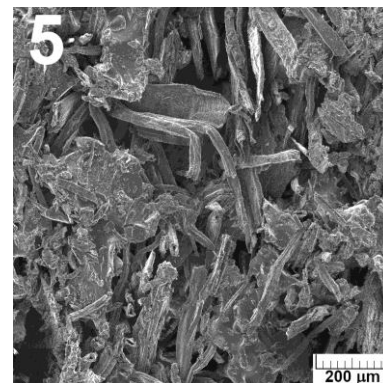
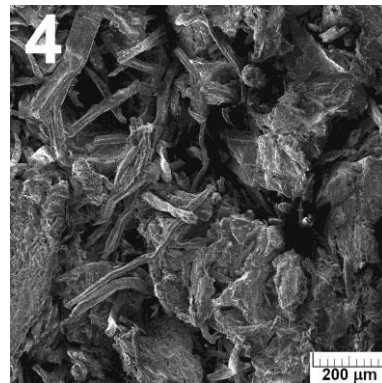
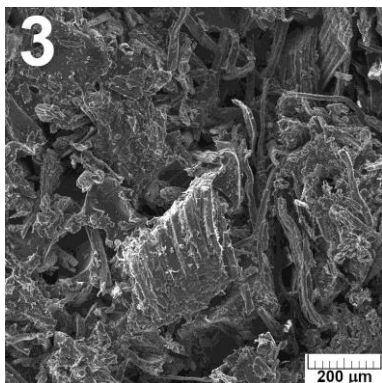
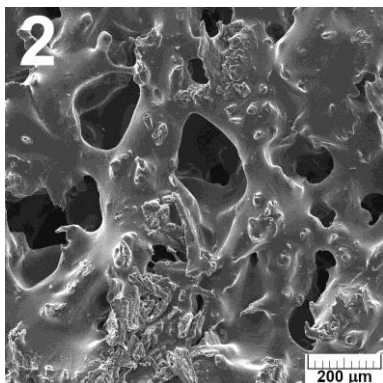
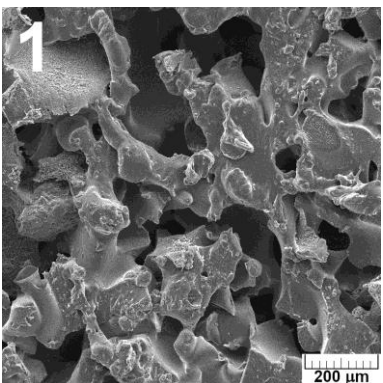
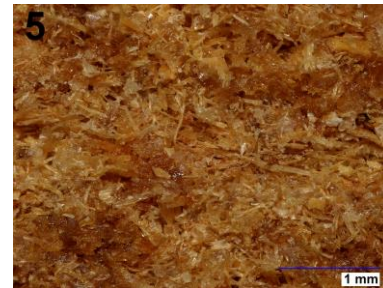
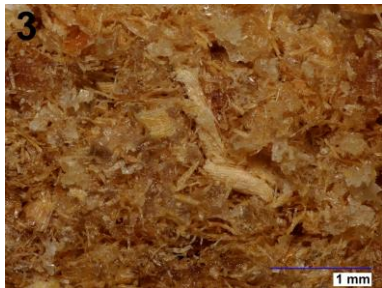
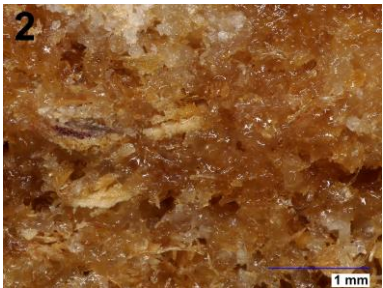
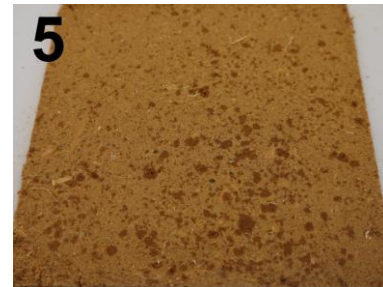
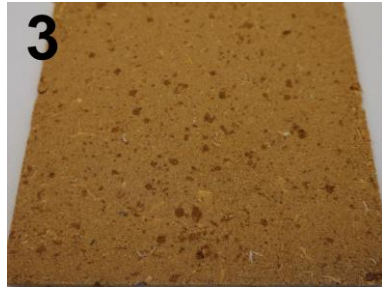
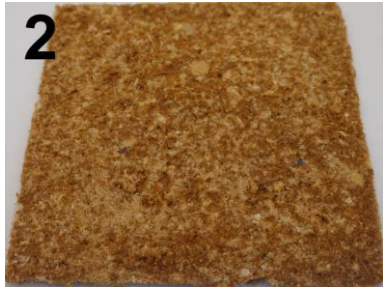


- (a) and (b) – main decomposition mechanisms of urethane groups
- (c) – ammonium bicarbonate thermal decomposition
- (d)-(f) – reactions between diisocyanate and PU decomposition products
- (g) and (h) – reactions between binder components
- (i) and (j) – additional crosslinking reactions





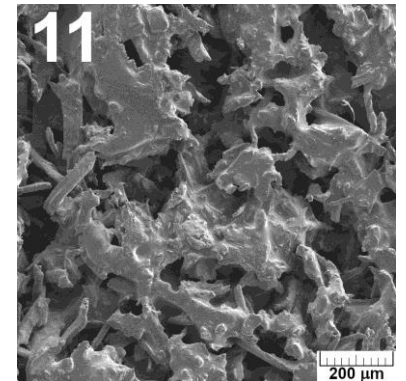
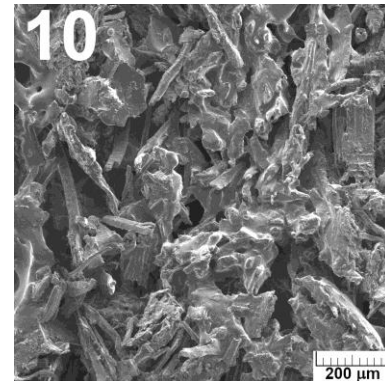
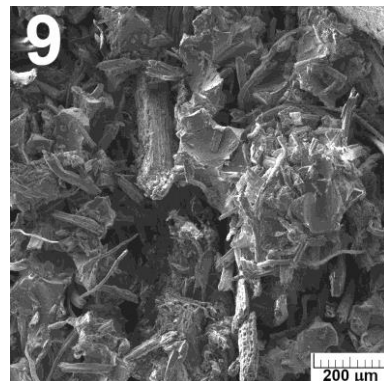
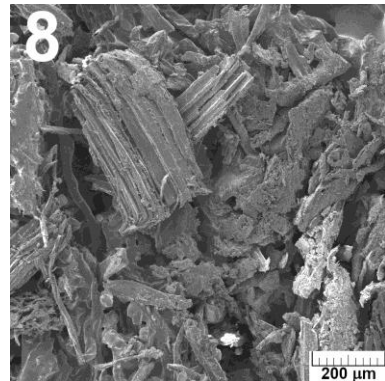
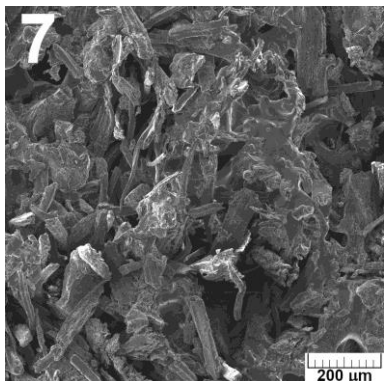
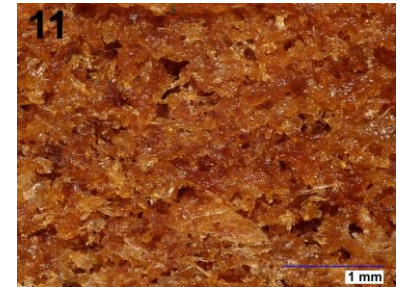
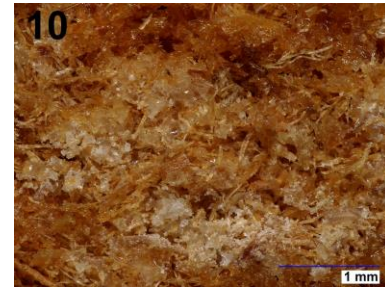
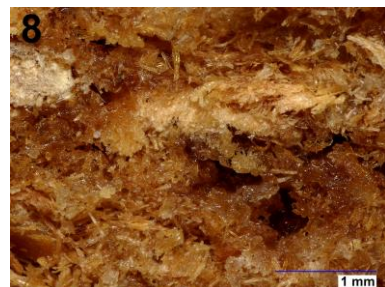
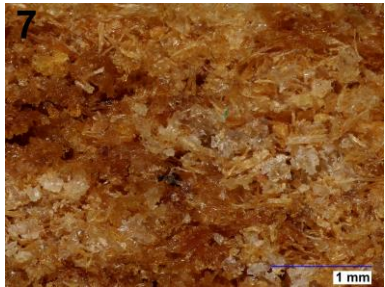
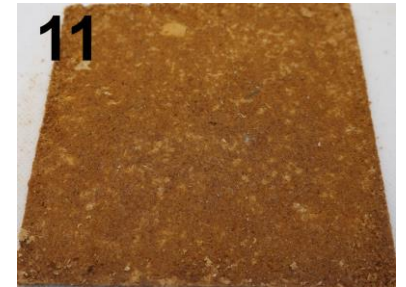
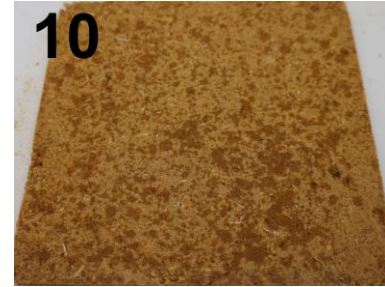
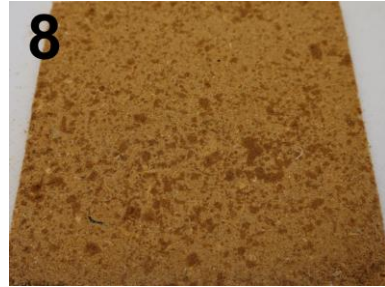
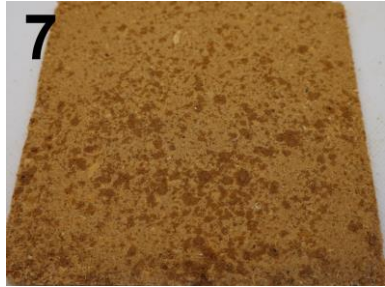
## Composites appearance and morphology – different waste ratio and binder content







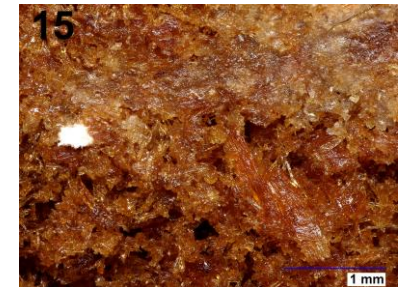
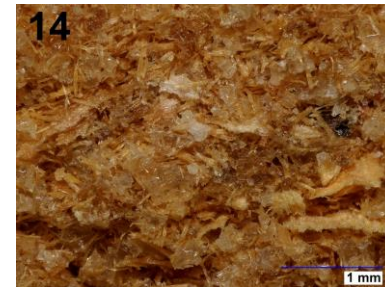
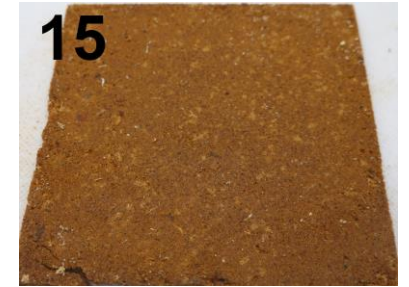
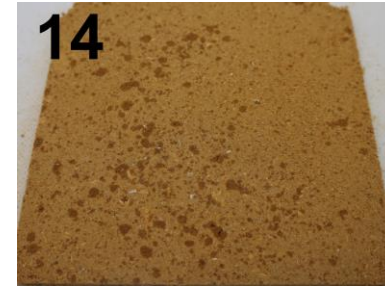
## Composites appearance and morphology – different binder composition



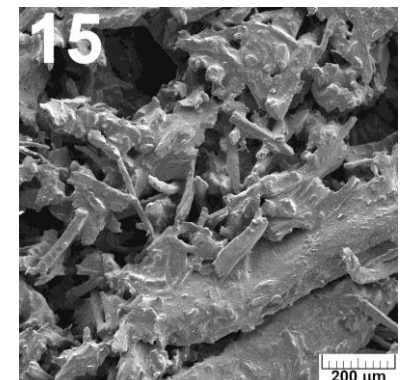
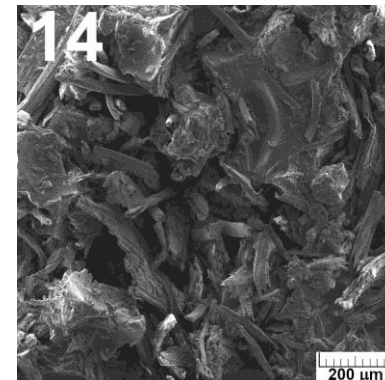
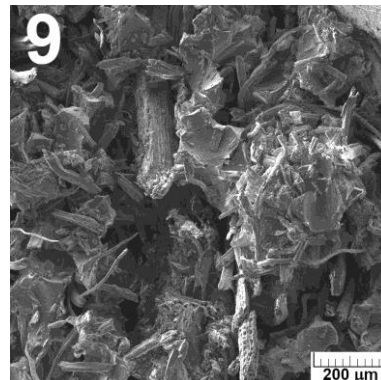




## Composites appearance and morphology – different compression temperature



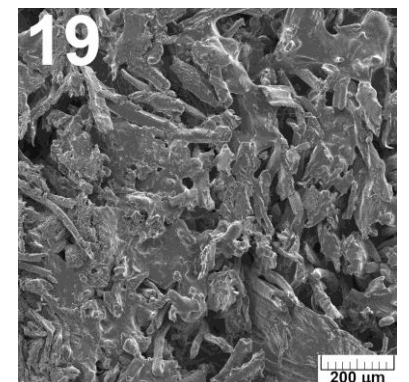
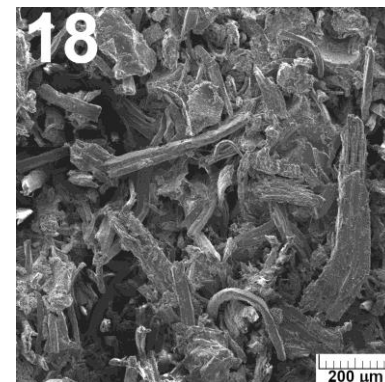
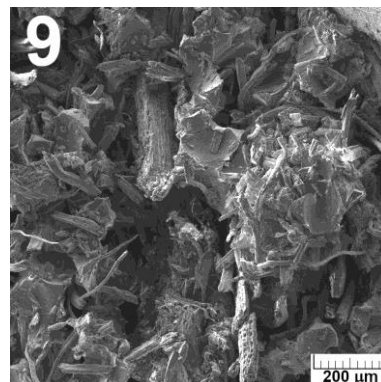
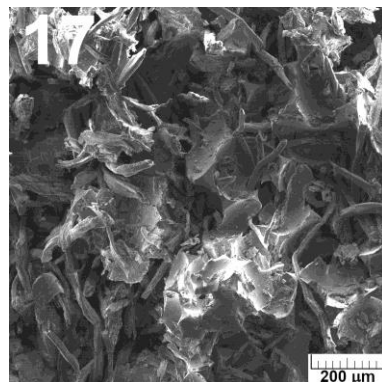
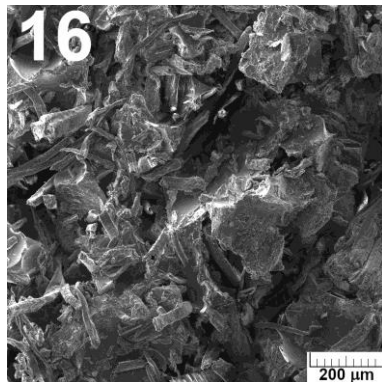
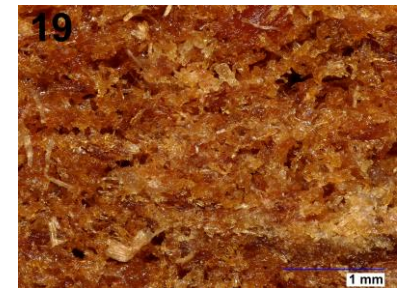
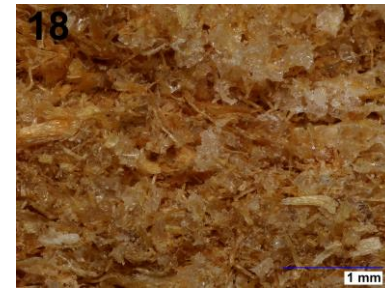
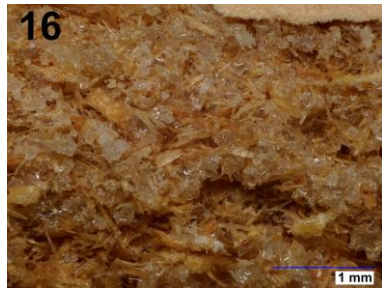
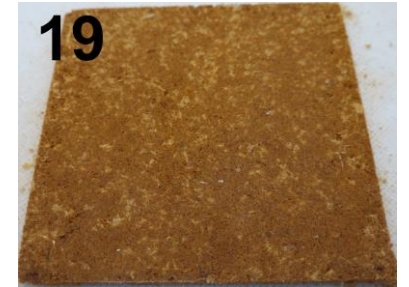
**Analysis not possible, samples too fragile**







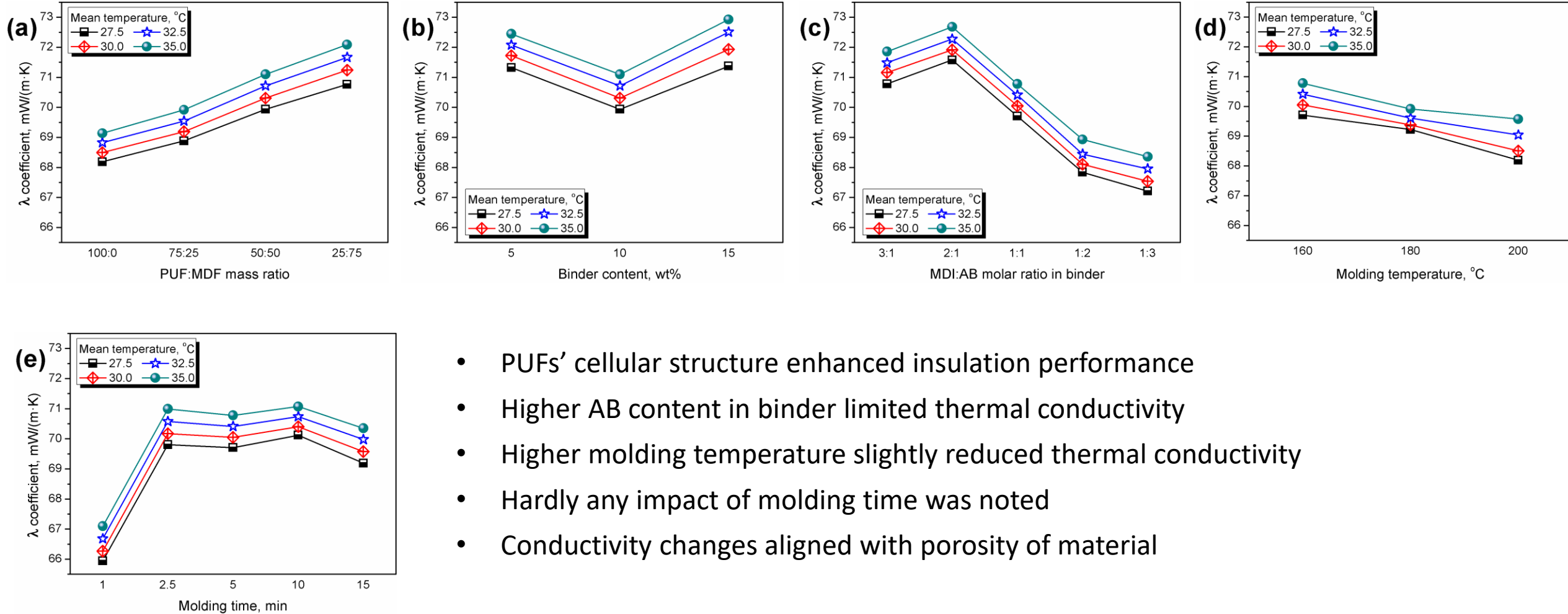
## Composites appearance and morphology – different compression time







## Composites thermal conductivity



- PUFs' cellular structure enhanced insulation performance
- Higher AB content in binder limited thermal conductivity
- Higher molding temperature slightly reduced thermal conductivity
- Hardly any impact of molding time was noted
- Conductivity changes aligned with porosity of material



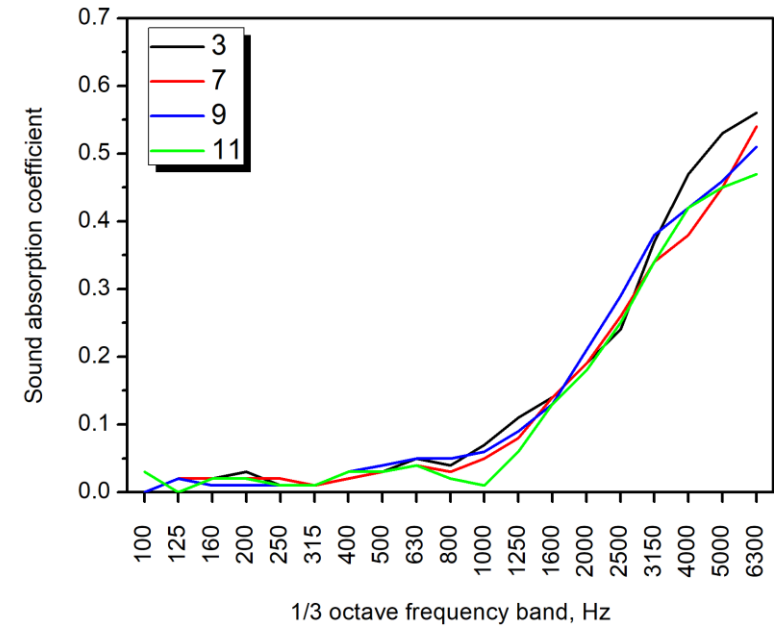
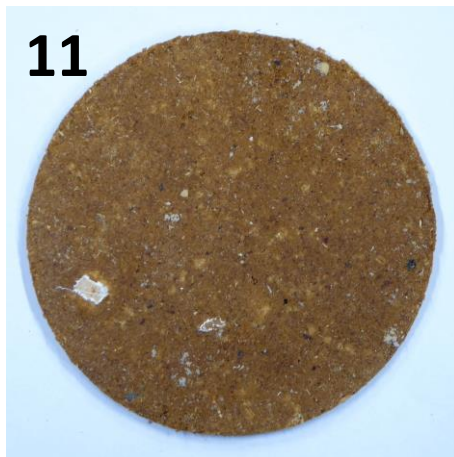
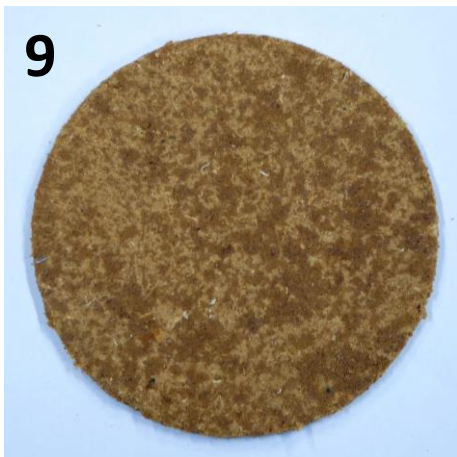
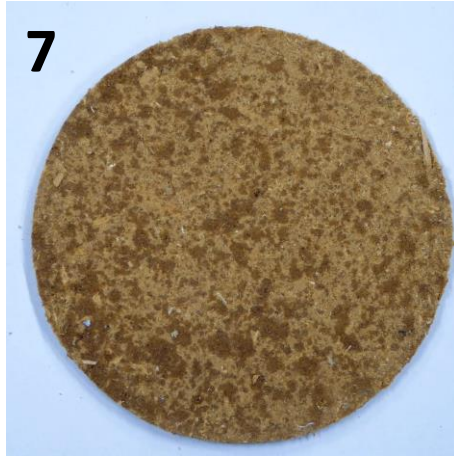
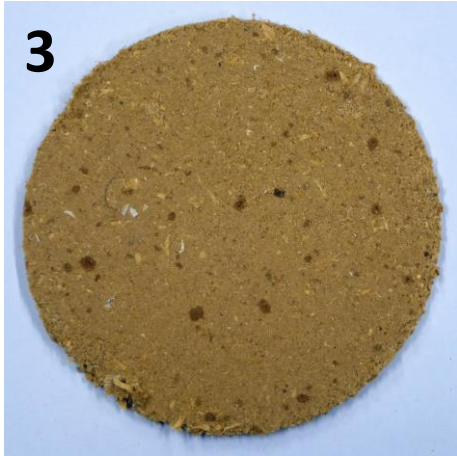
## Composites mechanical performance

Sample	Flexural strength, kPa	Deformation at flexural strength, %	Hardness, Sh0
1	-	-	51.3 ± 3.3
2	-	-	57.9 ± 4.5
3	204.7 ± 60.5	5.6 ± 1.1	76.8 ± 3.1
4	348.3 ± 71.6	1.6 ± 0.7	89.9 ± 3.8
5	61.9 ± 50.2	6.9 ± 1.7	72.1 ± 3.4
6	239.3 ± 47.6	3.9 ± 0.9	83.6 ± 4.0
7	232.7 ± 64.3	5.6 ± 0.7	81.7 ± 3.1
8	167.3 ± 14.6	5.5 ± 0.9	78.8 ± 3.9
9	153.7 ± 10.8	5.7 ± 1.1	75.1 ± 3.2
10	147.0 ± 4.5	5.4 ± 0.3	66.6 ± 3.3
11	95.1 ± 11.9	6.3 ± 1.9	62.7 ± 3.0
14	167.7 ± 11.1	5.1 ± 0.7	73.2 ± 2.9
15	195.0 ± 5.7	2.5 ± 0.7	67.2 ± 3.6
16	75.1 ± 6.3	5.5 ± 0.5	74.2 ± 4.0
17	164.5 ± 3.7	5.6 ± 1.5	76.2 ± 2.5
18	120.2 ± 4.3	6.9 ± 1.2	76.4 ± 2.7
19	77.7 ± 13.2	6.2 ± 1.3	65.2 ± 4.6

- Samples 1 and 2 – flexural test not possible
- Hardness mostly enhanced by MDF content and MDI loading
- Mechanical properties driven by the extent of PUF phase thermal decomposition



## Composites acoustic performance

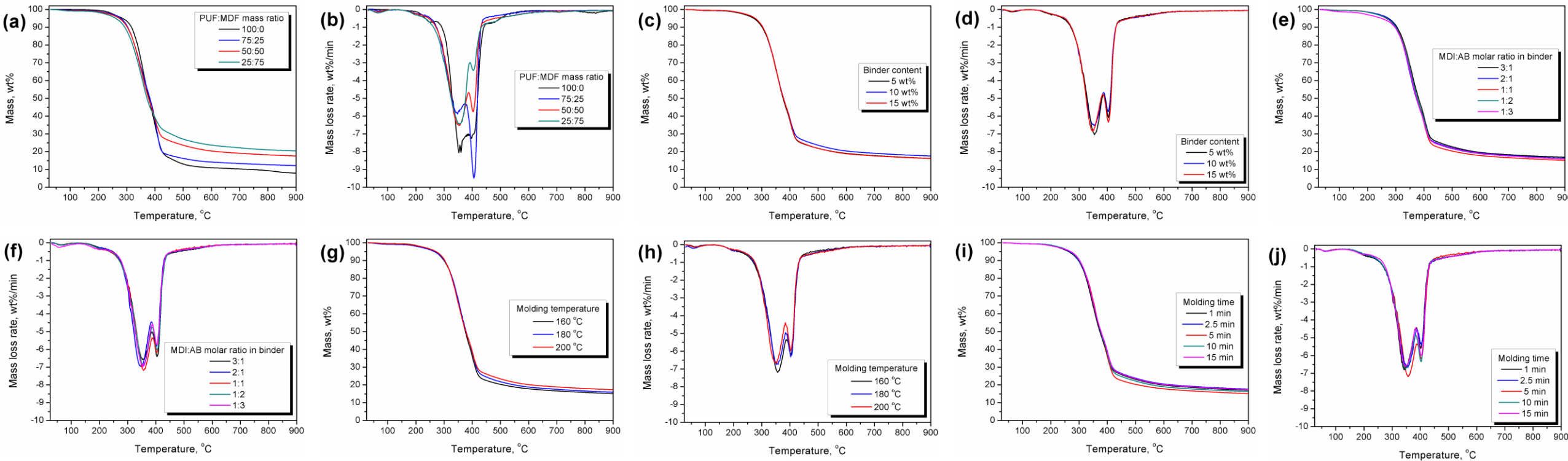


- Relatively similar acoustic performance
- Sound absorption enhanced at higher frequencies
- Could be applied as auxiliary material above 4 kHz





## Composites thermal stability



- Higher MDF content increased char residue amount
- At the same time, decomposition onset shifted from 243 °C to 209 °C
- Higher binder content slightly enhanced thermal stability
- Excessive AB loading reduced thermal stability



## **Conclusions and future remarks**

- **Efficient recycling process with novel binder composition using simple process of compression molding,**
- **Reduced amount of conventionally applied diisocyanate required,**
- **PU phase decomposition extent driven by the MDI/AB ratio,**
- **Potential applications of PU foams as waste-based binder for engineered wood materials,**



Rhodes 2024 - 11<sup>th</sup> International Conference on Sustainable  
Solid Waste Management



# Thank you!

**INNOGOW - Supporting innovation in bulky waste management**

(Science for the Society II, NdS-II/SP/0039/2024/01)

