Recycling Bio composites

Exploring the possibilities of recycling bio composites into filler for a new bio composite façade product.

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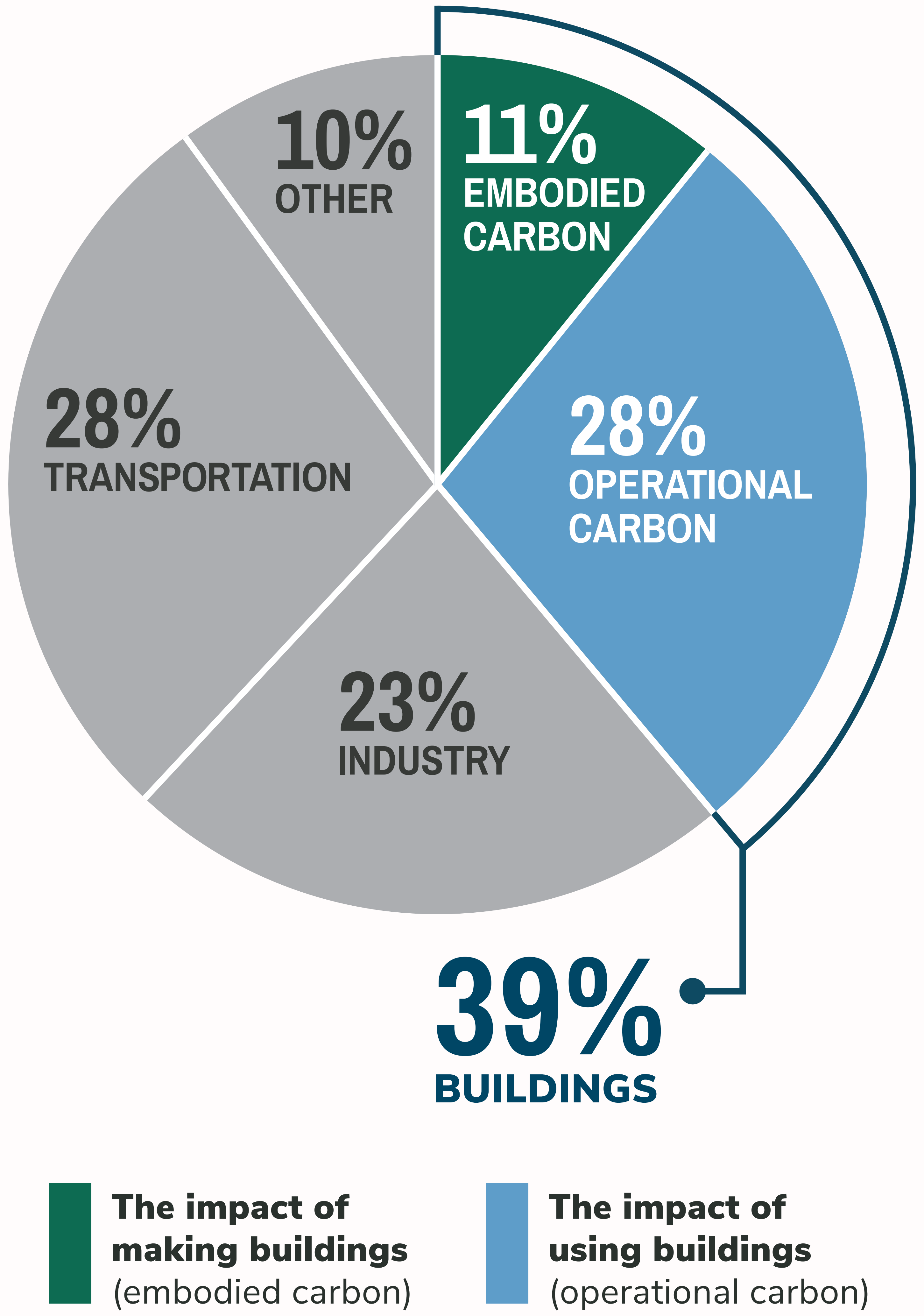
ANNUAL GLOBAL CO_2 EMISSIONS



Source: Global Alliance for Buildings and Construction, "Global Status Report 2017"

Embodied carbon building

→ 20%

Embodied carbon building

Embodied carbon building

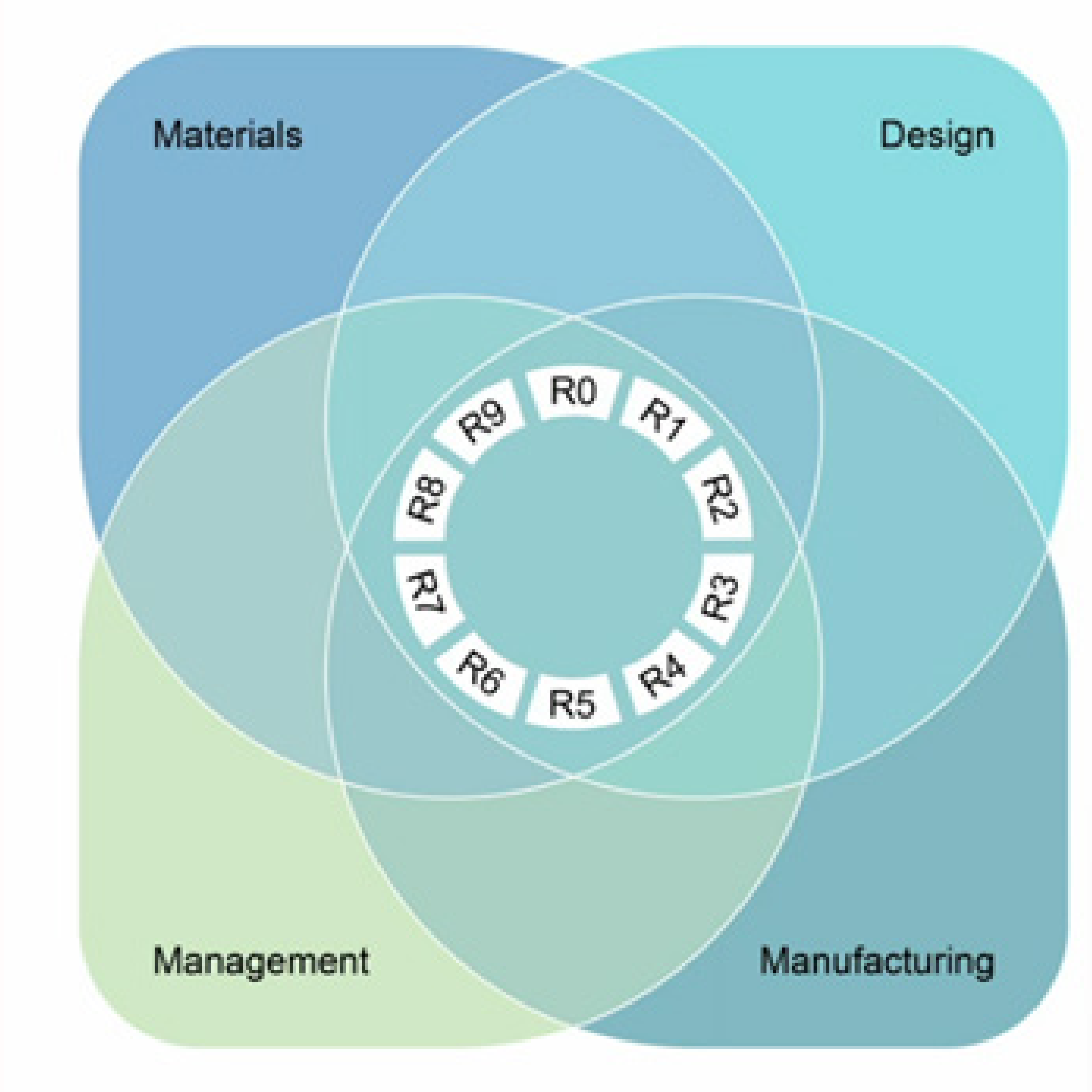
Embodied carbon building

Circular building products

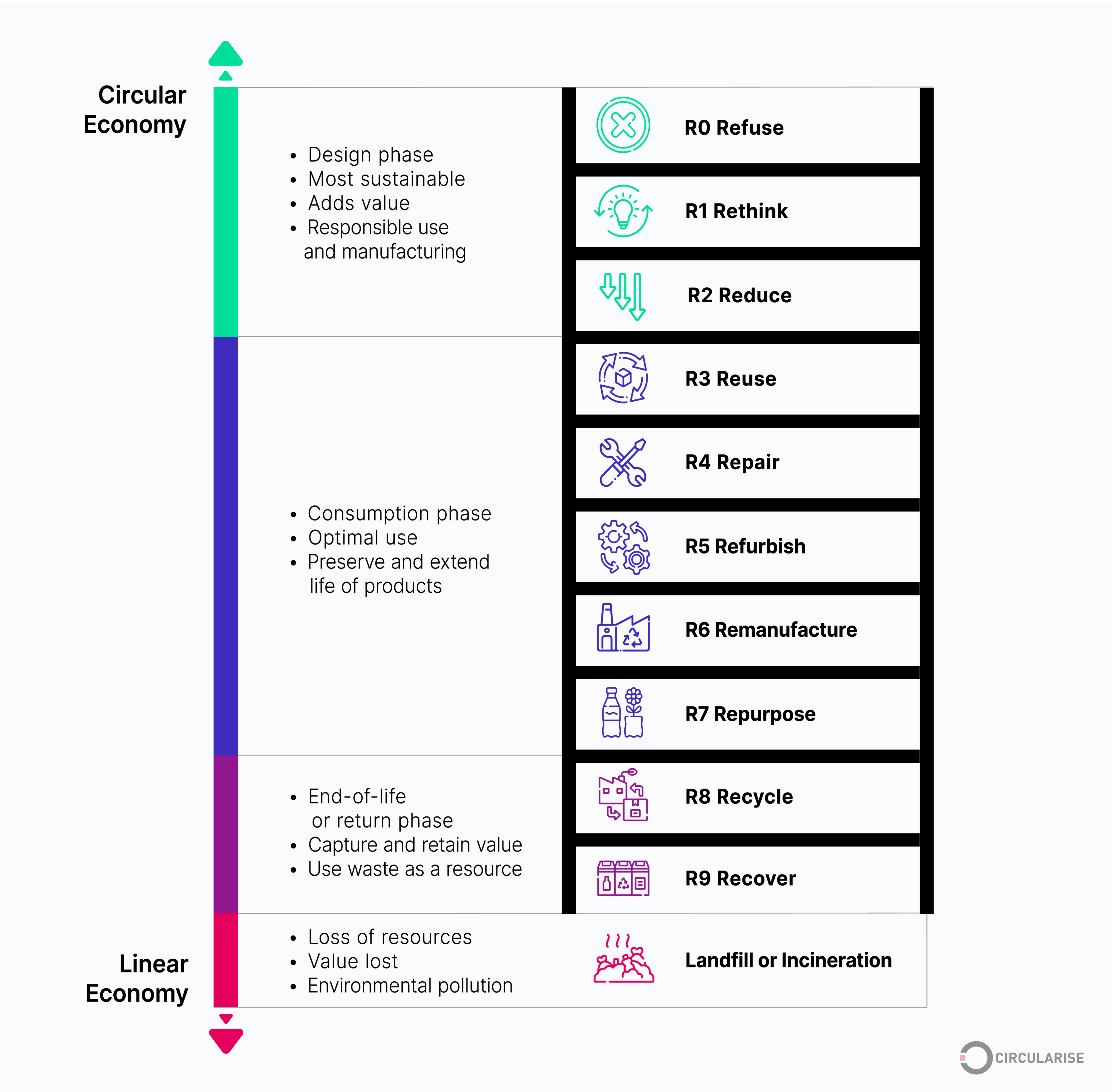
Reduce waste

Extent life cycle

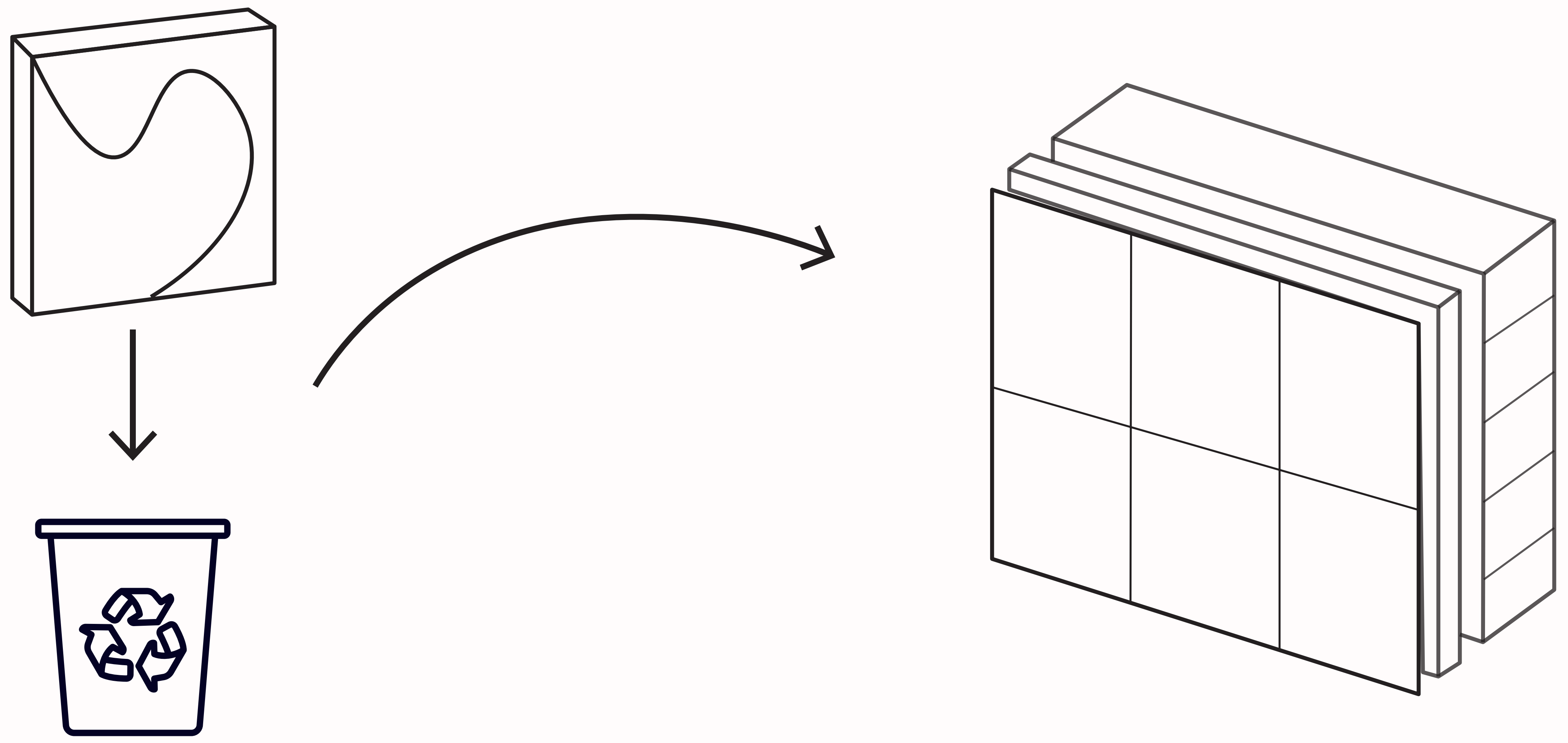
Smart design choices



R-strategies



Concept

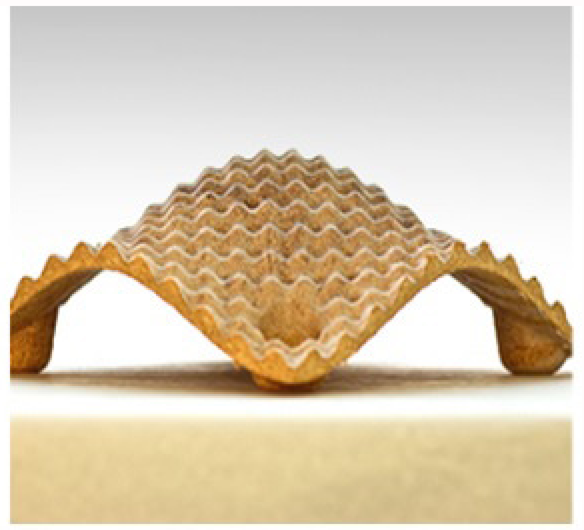


Bio composites

Bio composites

"Material made from two or more materials"



Bio composites

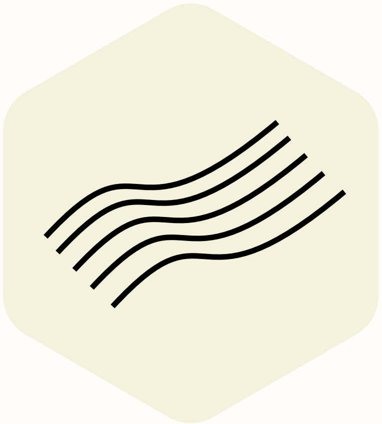
Matrix

Thermoplastic
Thermoset

Fillers

Bulk fillers
Functional fillers

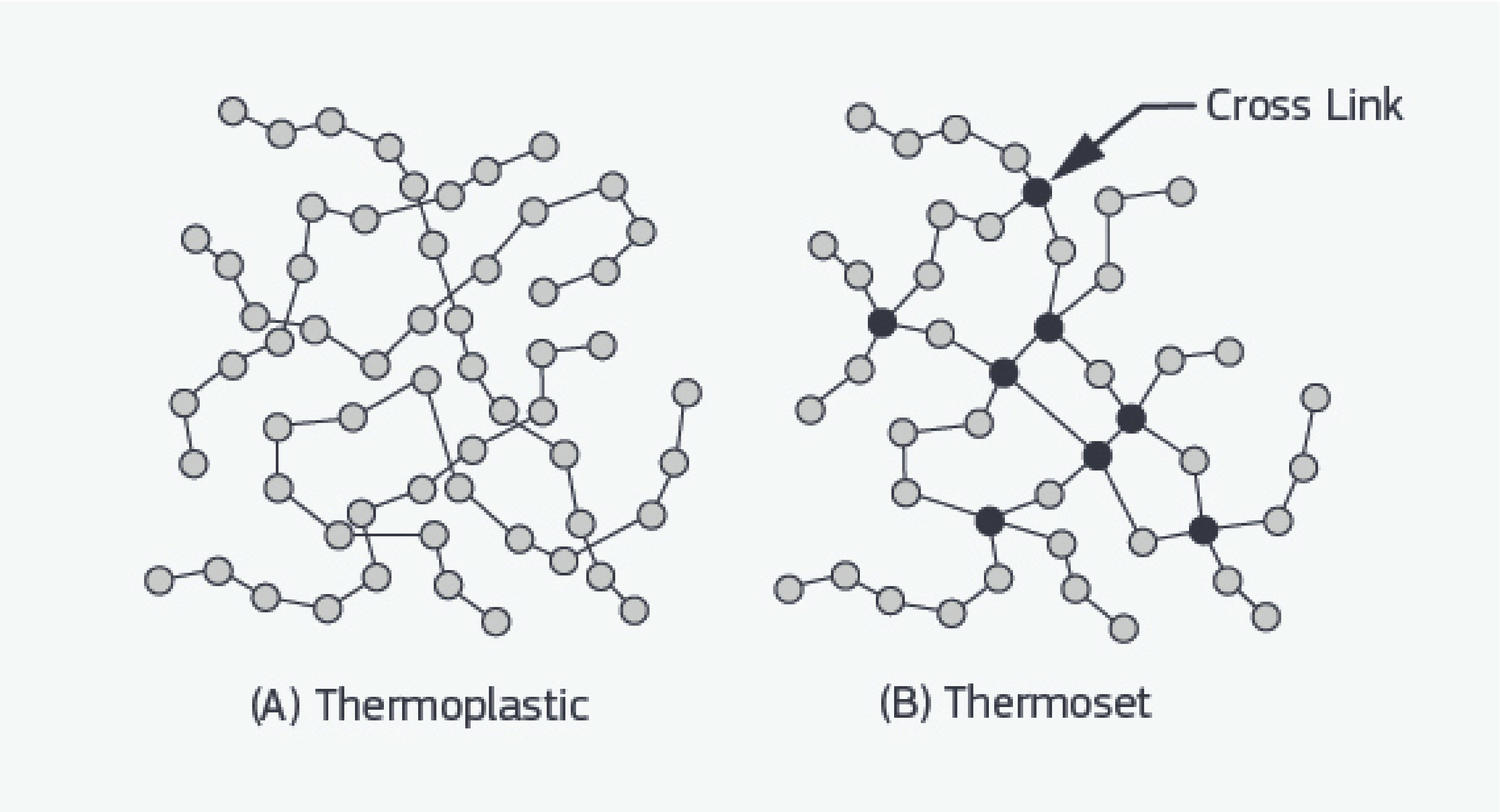
Fibres



Oriented
Random

Bio plastic matrices

- Thermoplastic
- Thermoset



Fillers

Bulk fillers (40-65wt%)

- Reduce cost
- Increase strength

Functional filler (<5wt%)

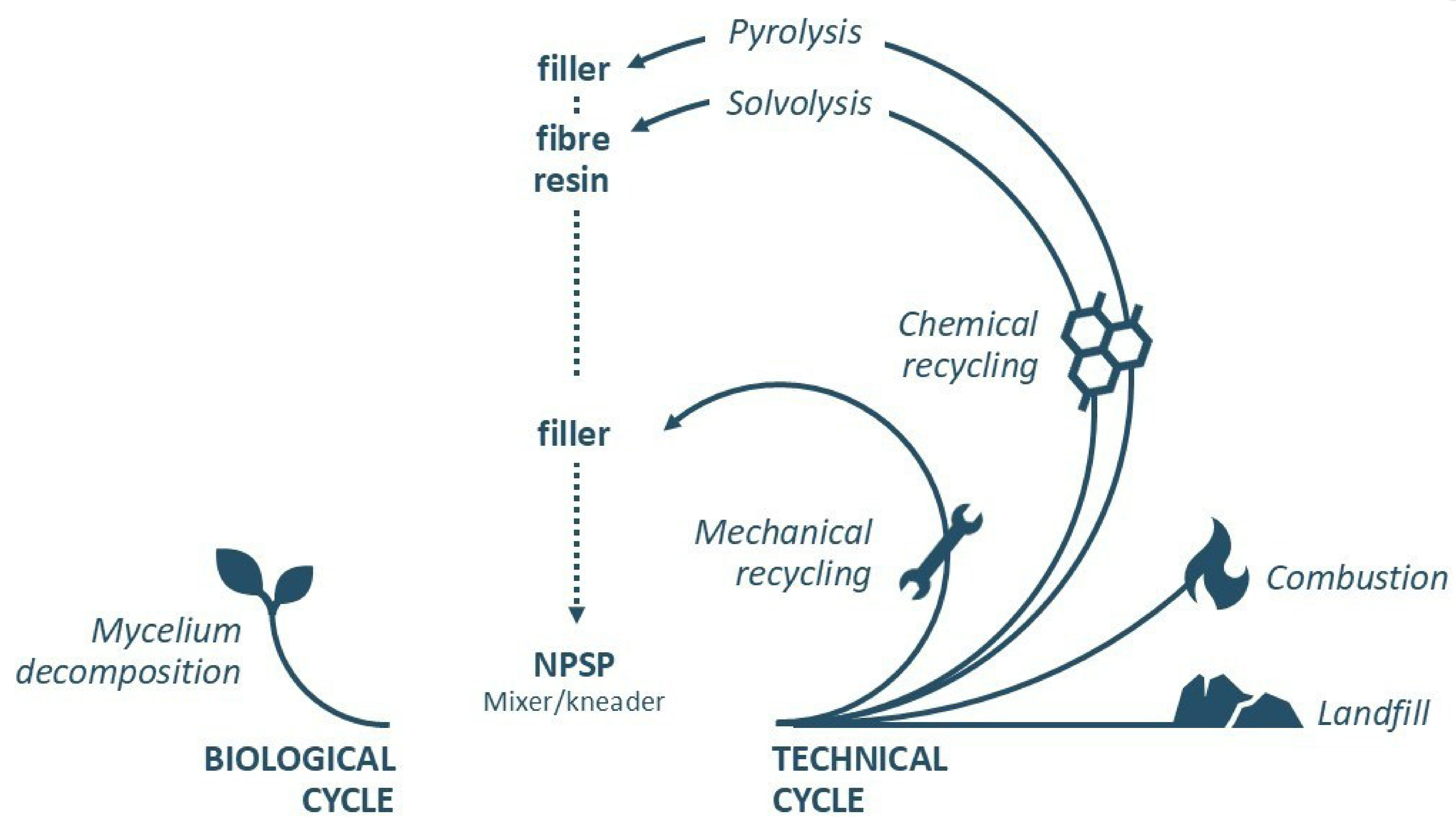
- Fire resistance
- Pigments
- Release agents

Fibres

- Reinforcement
- Reduce shrinkage

Natural fibres

Recycling


Pyrolysis
filler
Solvolysis
fibre
resin
Chemical
recycling
filler
Mechanical
recycling
Combustion
Mycelium
decomposition
NPSP
Mixer/kneader
Landfill
BIOLOGICAL
CYCLE
TECHNICAL
CYCLE

Research questions

“How can bio composite facade panels be recycled into new bio composite panels after their end of service life?”

Sub questions

- What are the **key performance properties** of recycled bio composite façade panels?

- How do recycled filler materials **compare** to virgin raw filler materials used in current bio composite panels?

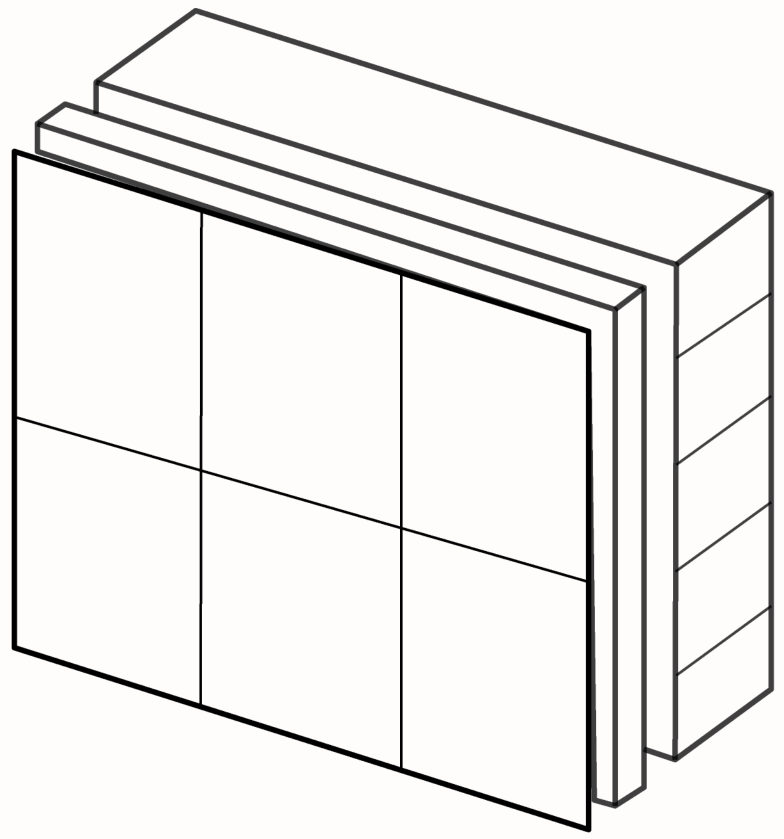
- How does the **weathering** of the pre-recycled panel influence the performance of the recycled bio composite façade panel?

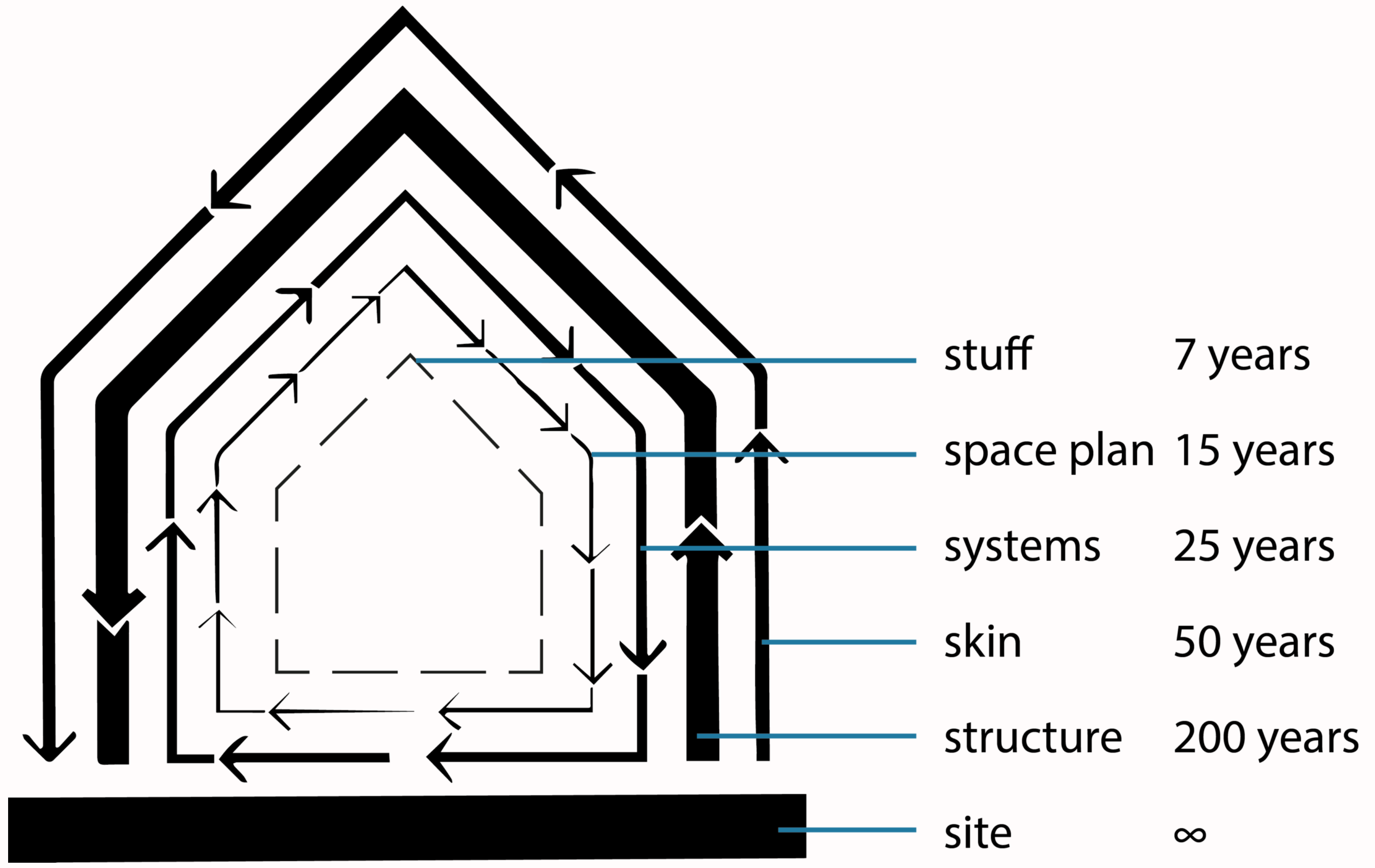
- How does using a recycled filler affect the **design** of a bio composite facade panel?

Application

Application

Rain screen façade panel



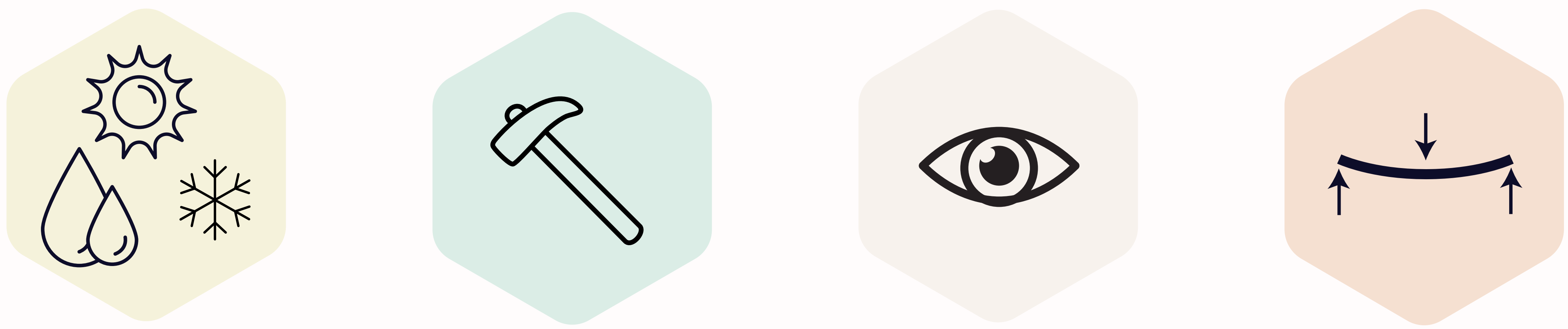


Scheme of shearing layers model, based on (Brand, 1994)

Application requirements

Requirements:

- Protection from **weather**
- **Impact** resistance
- Aesthetic **appearance**
- **Bending strength** against wind load



Material selection

Bio composites

Matrix

Furan resin

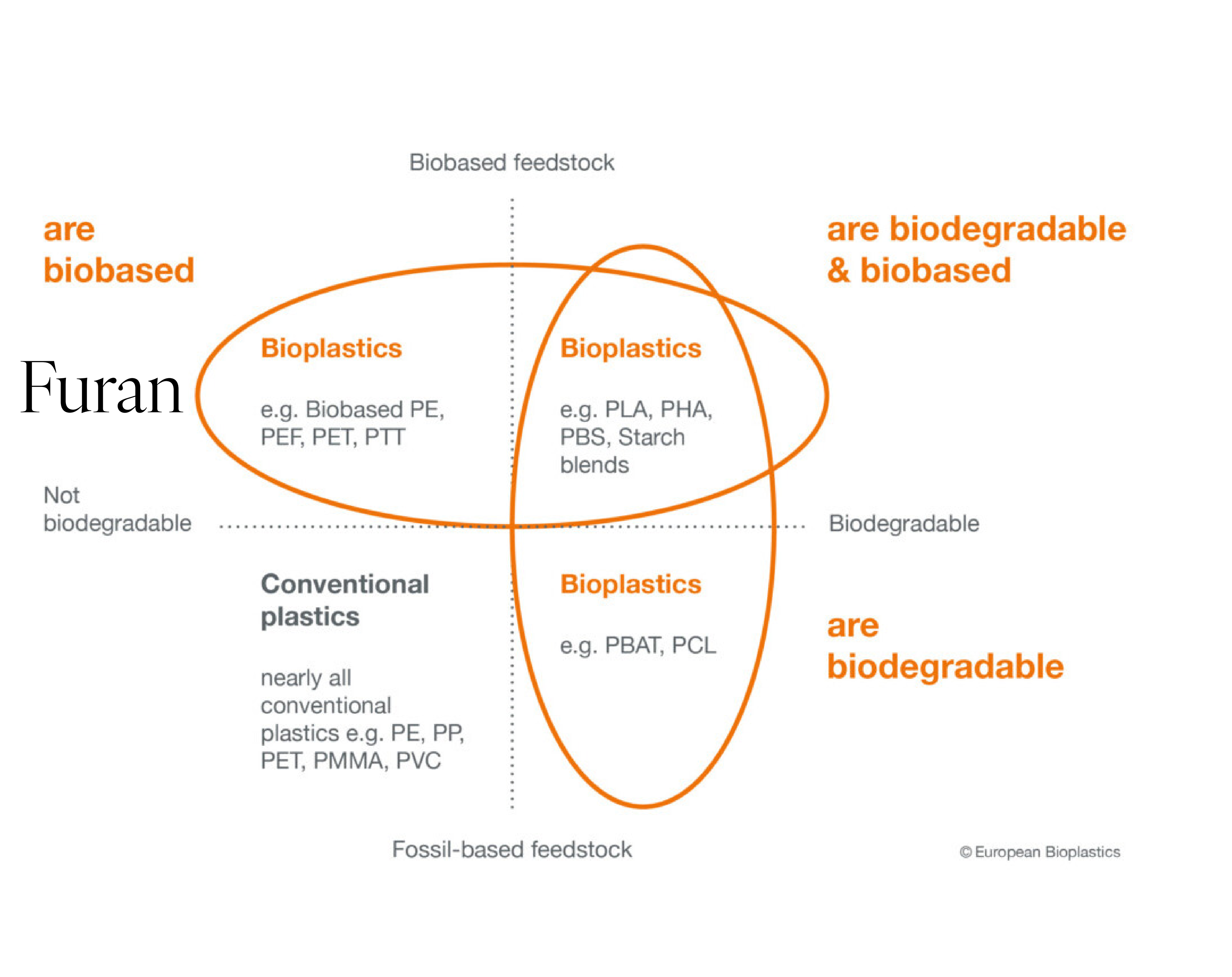
Fillers

Almond shell

Components bio composite

Matrix: **Furan resin**

- Bio based
- Not bio degradable
- Dark brown colour
- Thermoset



Components bio composite

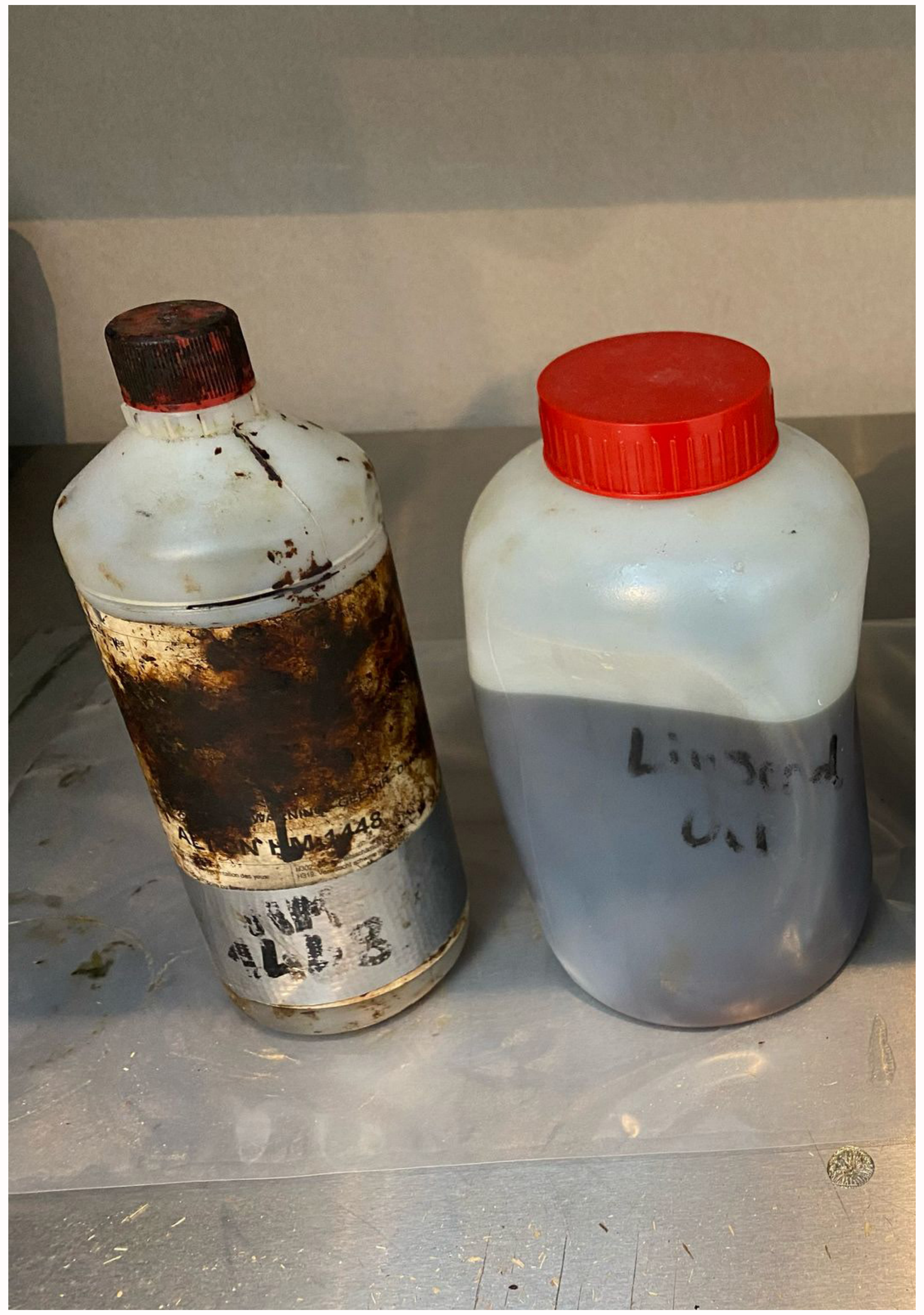
Additives:

Catalyst

Activates curing process

Linseed oil

Release agent

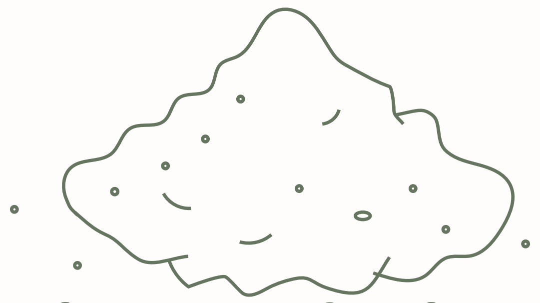


Base recipe

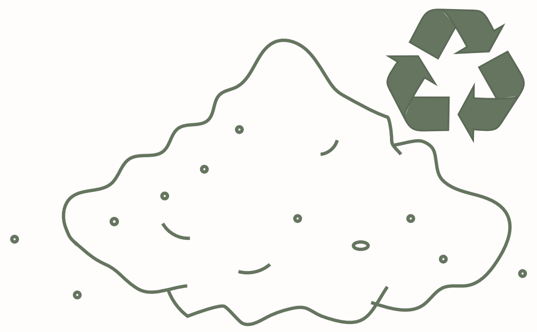
Component	Description	Weight [%]
Matrix	Furan	45
Filler	Almond shell	45
Catalyst		7
Release agent	Linseed oil	3

Fillers

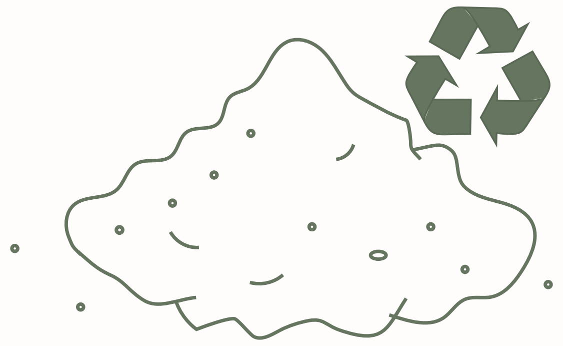
Filler types



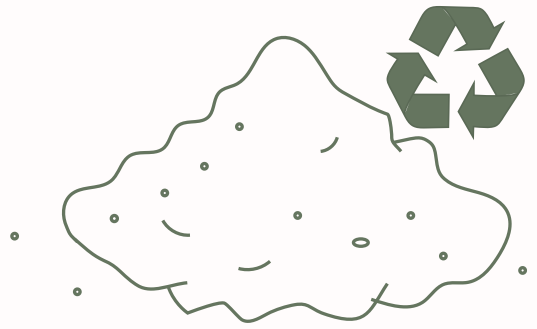
Almond Shell



NEW



OUT



QUV

Almond Shell

Almond shell

Almond shells

Filler ASF

NEW

Recycled filler NEW

Sample plate base recipe

Filler RF_NEW

Recycled filler OUT

Facade panel outside

Filler RF_OUT

Recycled filler QUV

Sample plate QUV

Filler RF_QUV

Filler preparation

Filler preparation

Step 1: Hammering sample plate into small pieces

Step 2: Shredding into smaller pieces

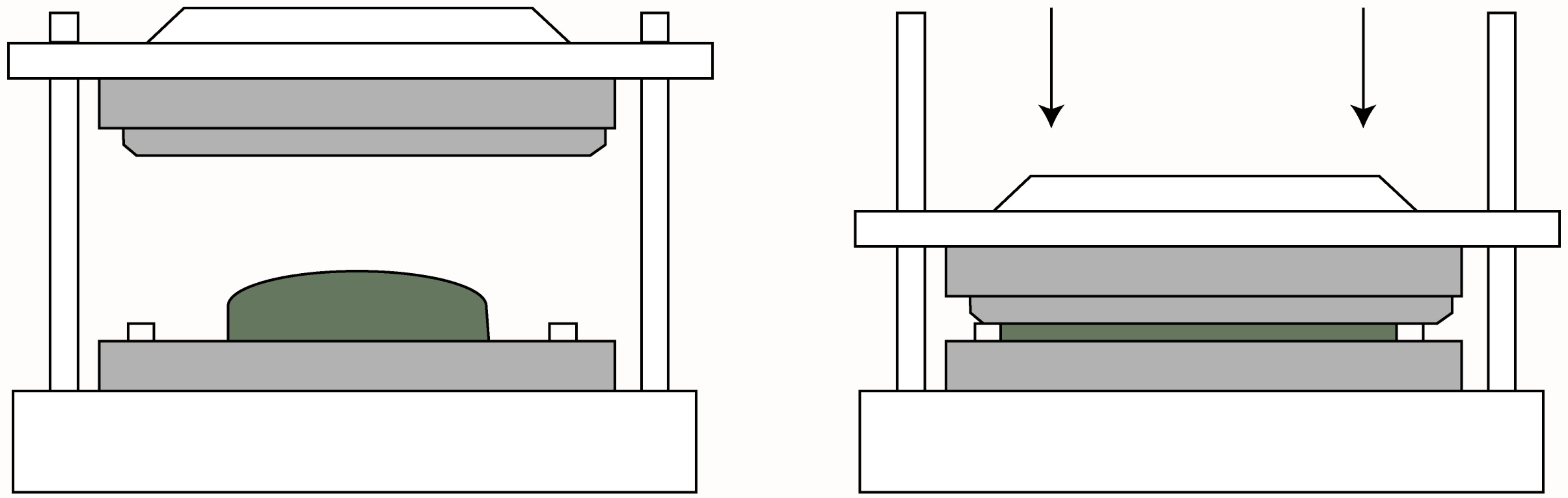
Filler preparation

Step 3: Milling into powder

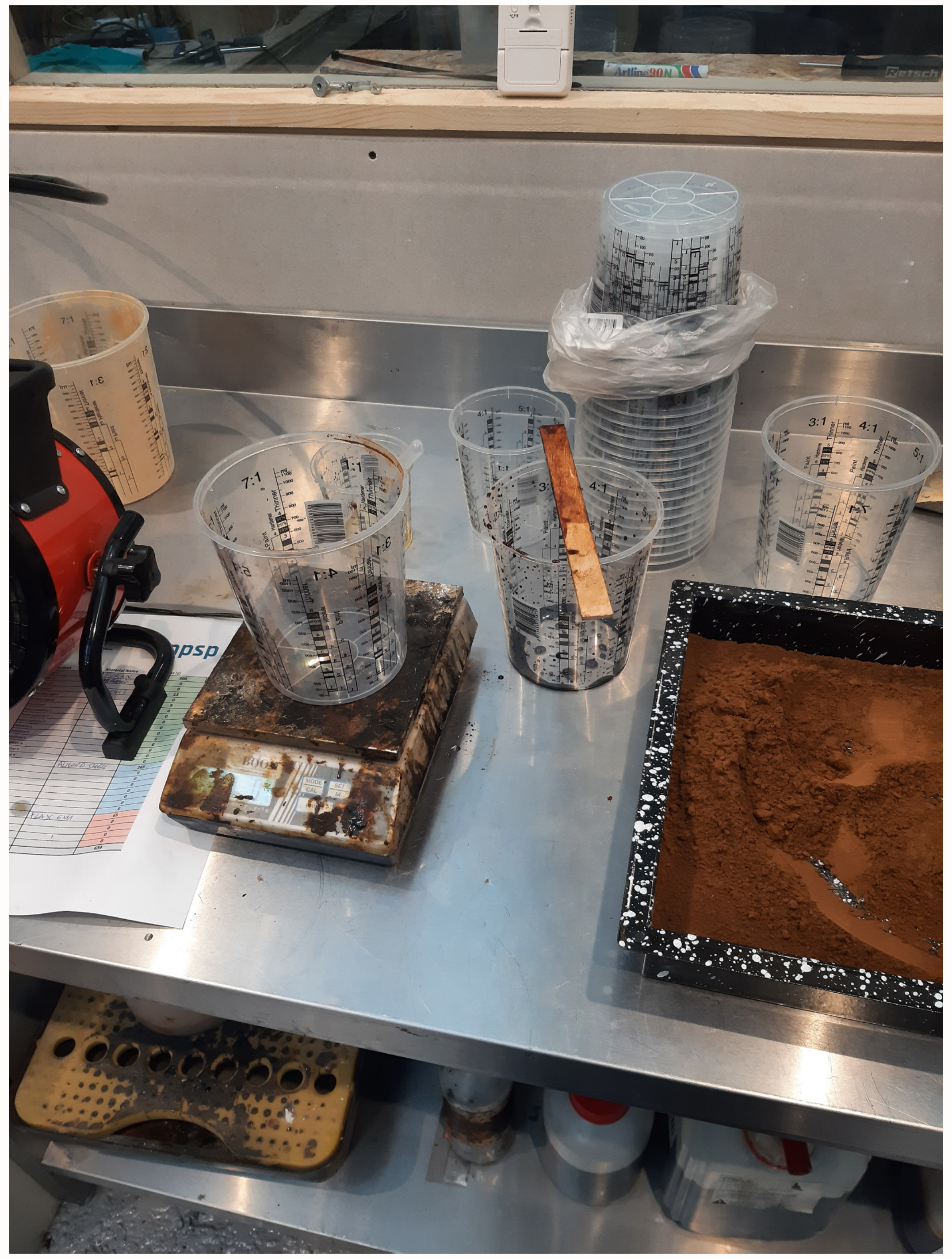
Manufacturing method

Manufacturing method

Bulk compression moulding



Process manufacturing

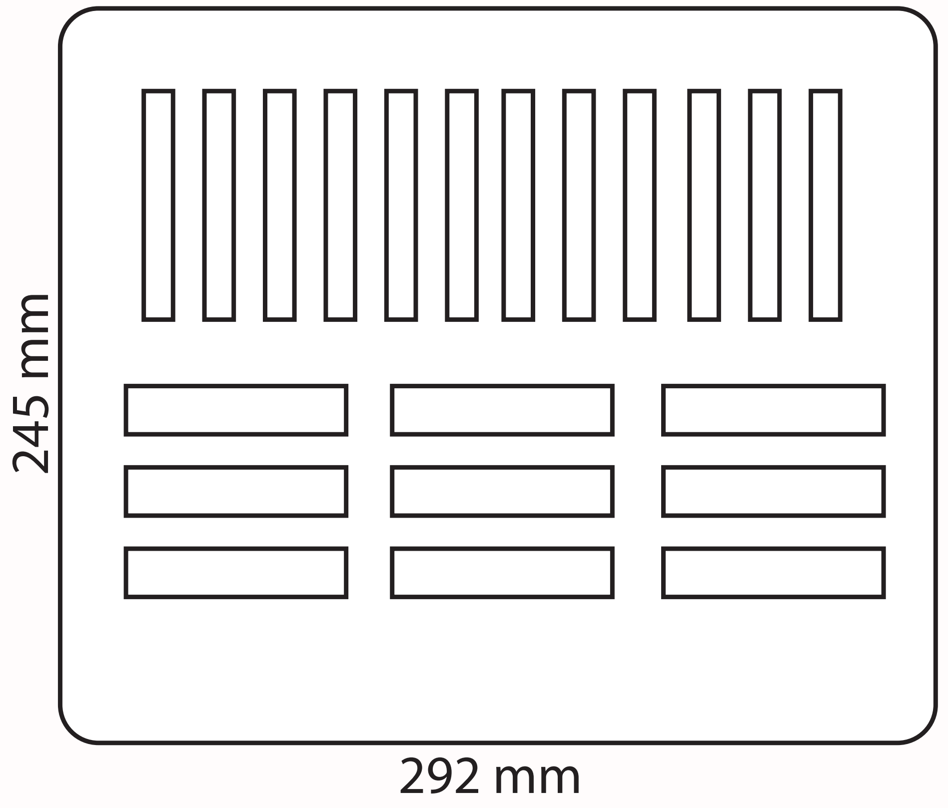



Step 1: Measuring ingredients & mixing

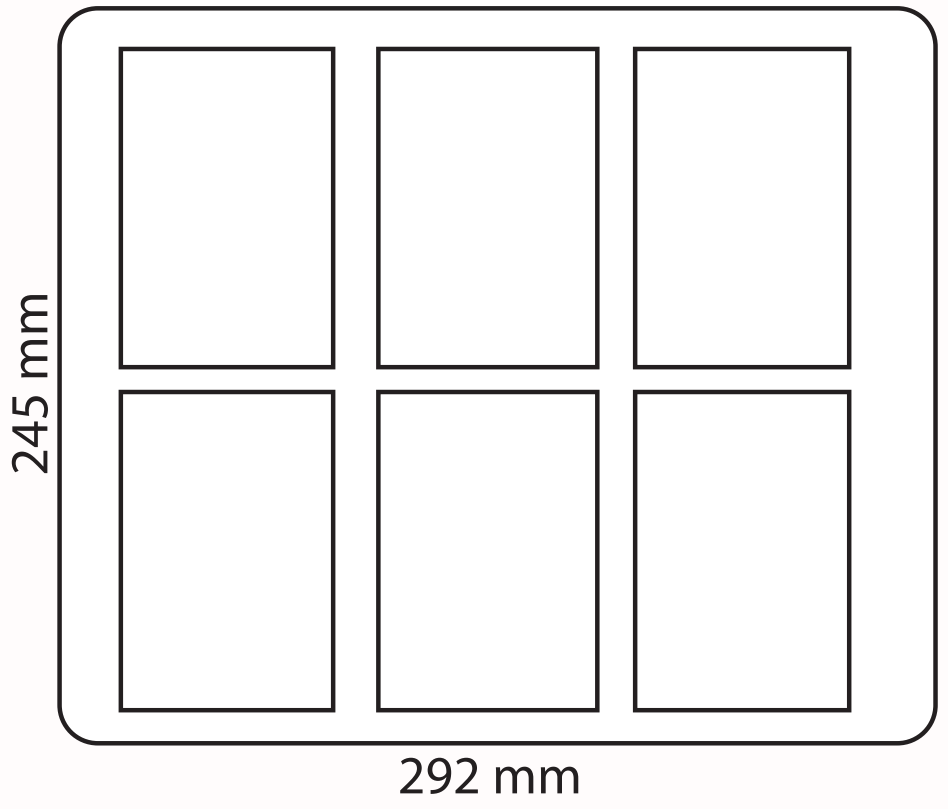
Step 2: Pressing sample plates

Process manufacturing

Step 3: CNC plates for testing



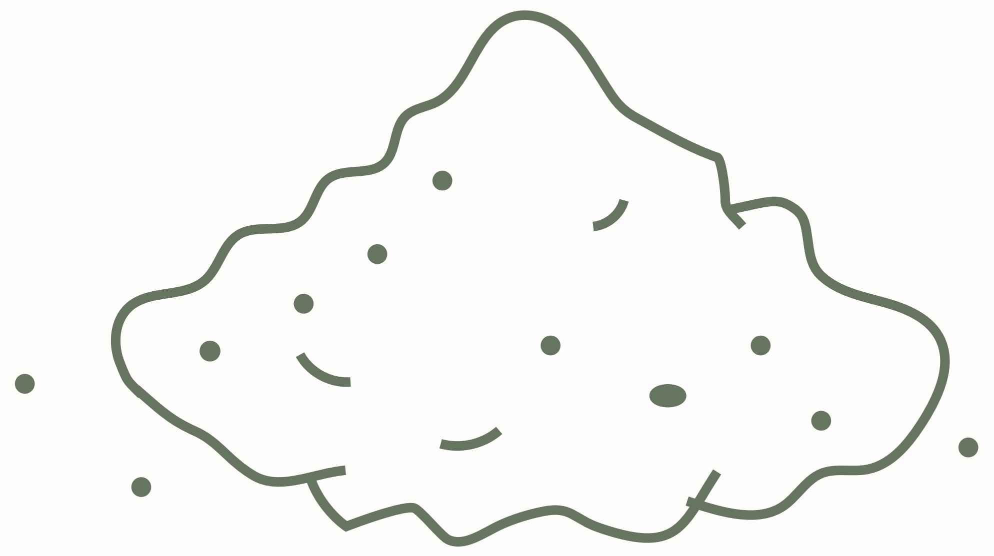
- 9 Flexural strength
- 12 Impact test



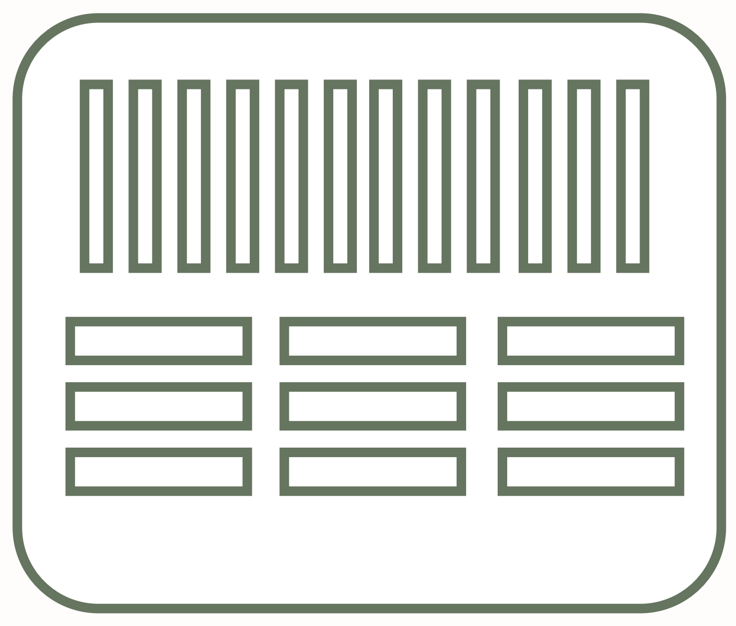
- 2 QUV
- 2 Watersubmersion
- 1 Frost resistace
- 1 Reference

Methodology

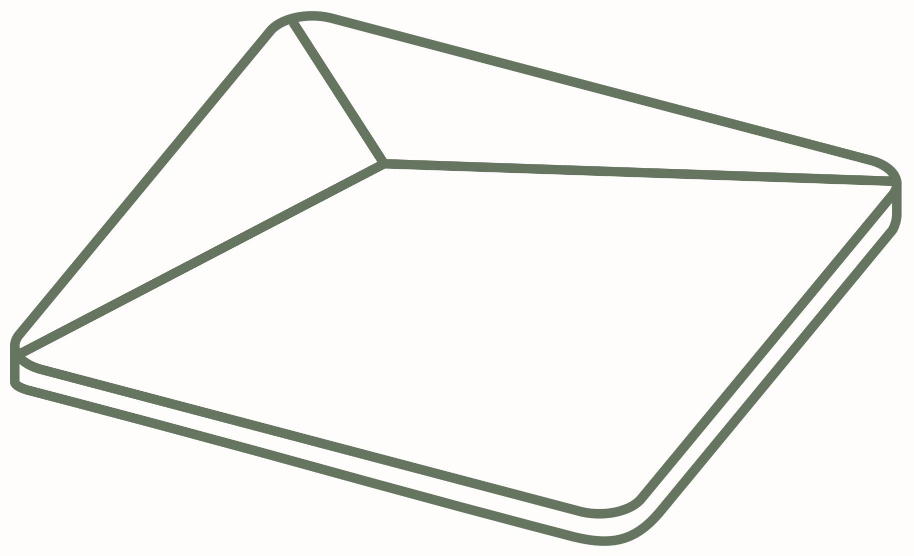
Structure



Raw material resources

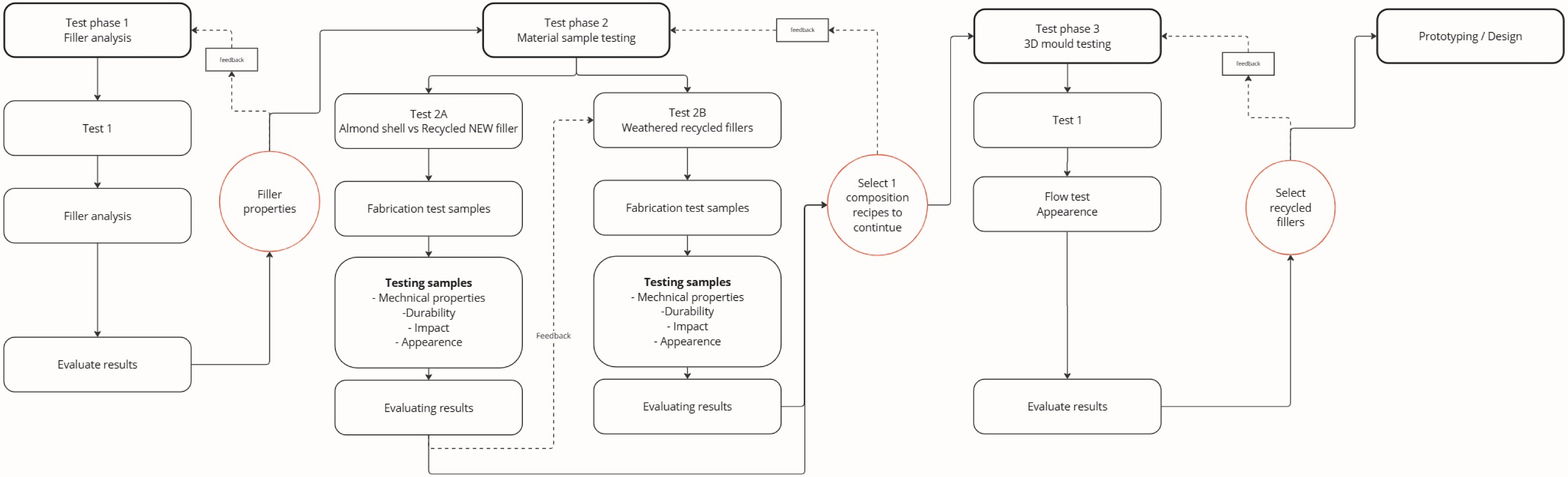


Material sample



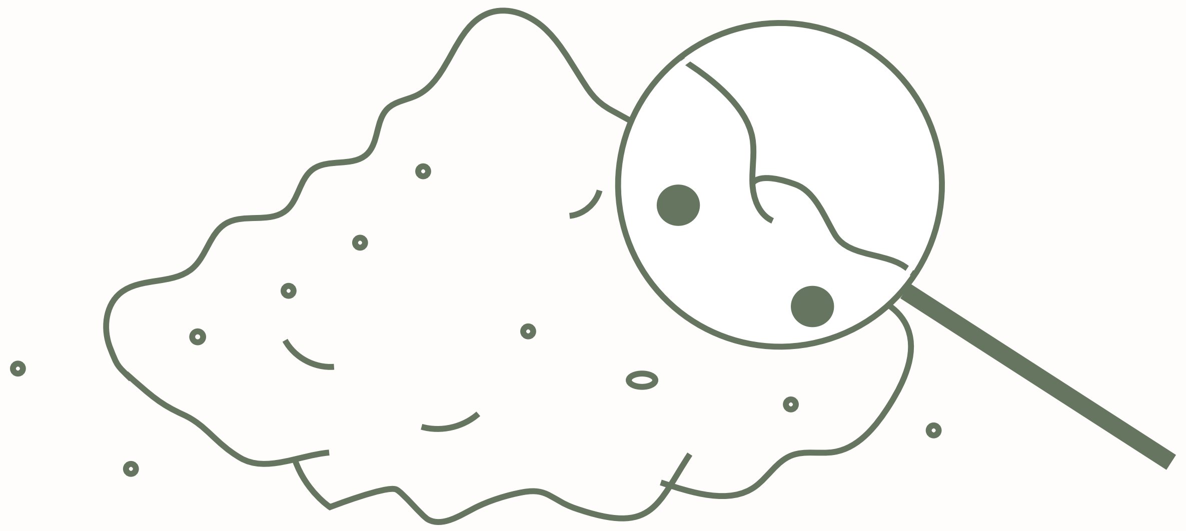
Product sample

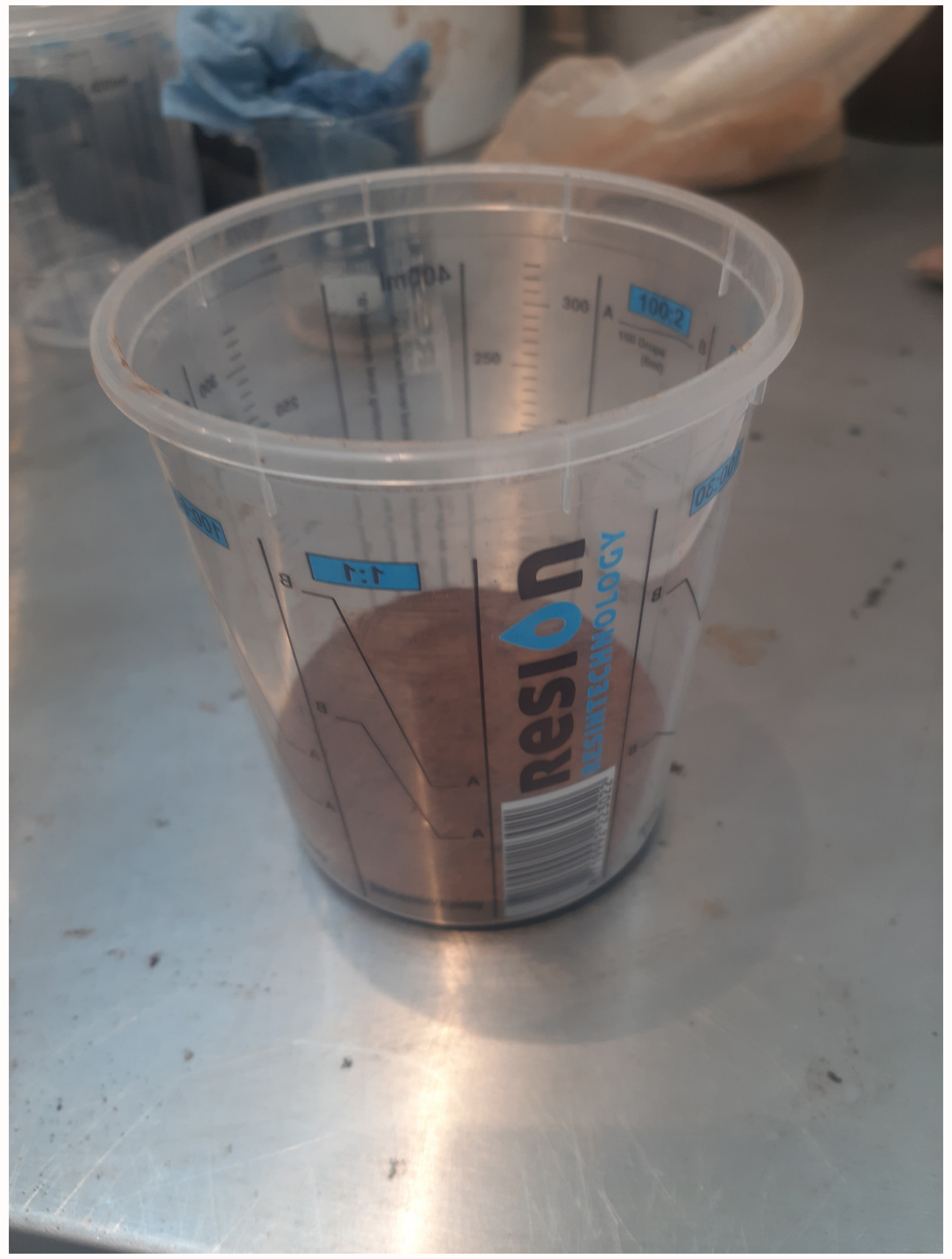
Testing workflow

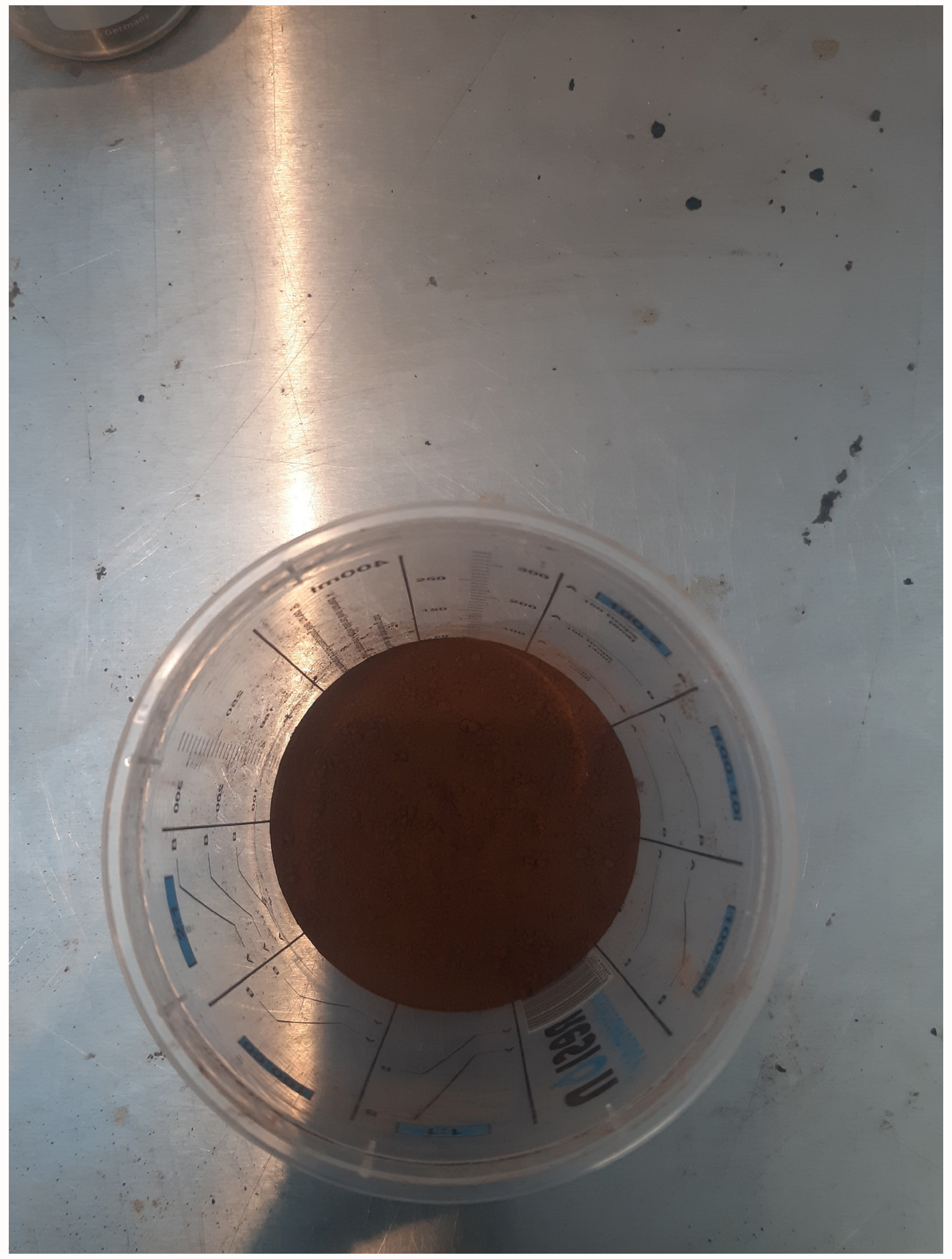


Testing phases

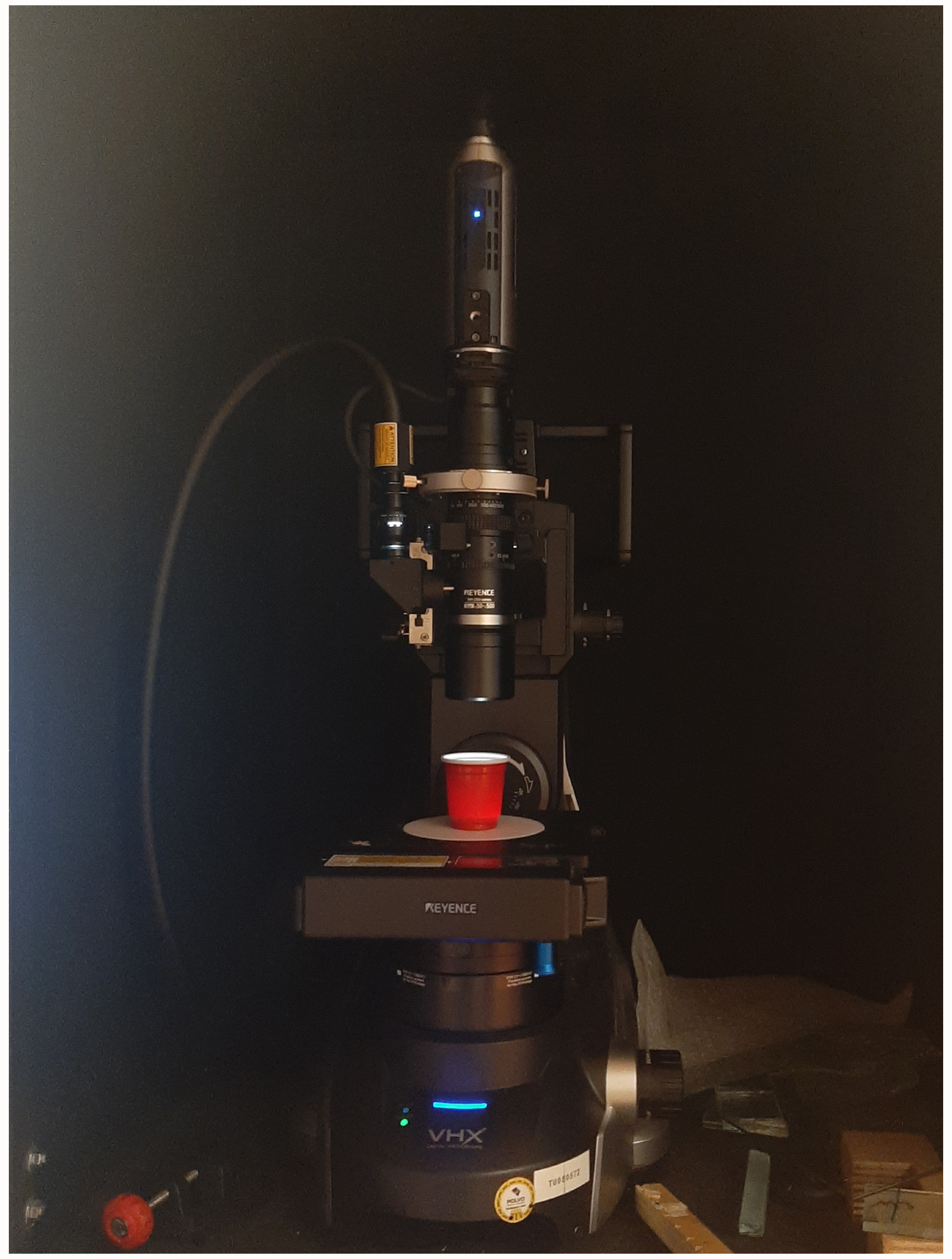
Testing process





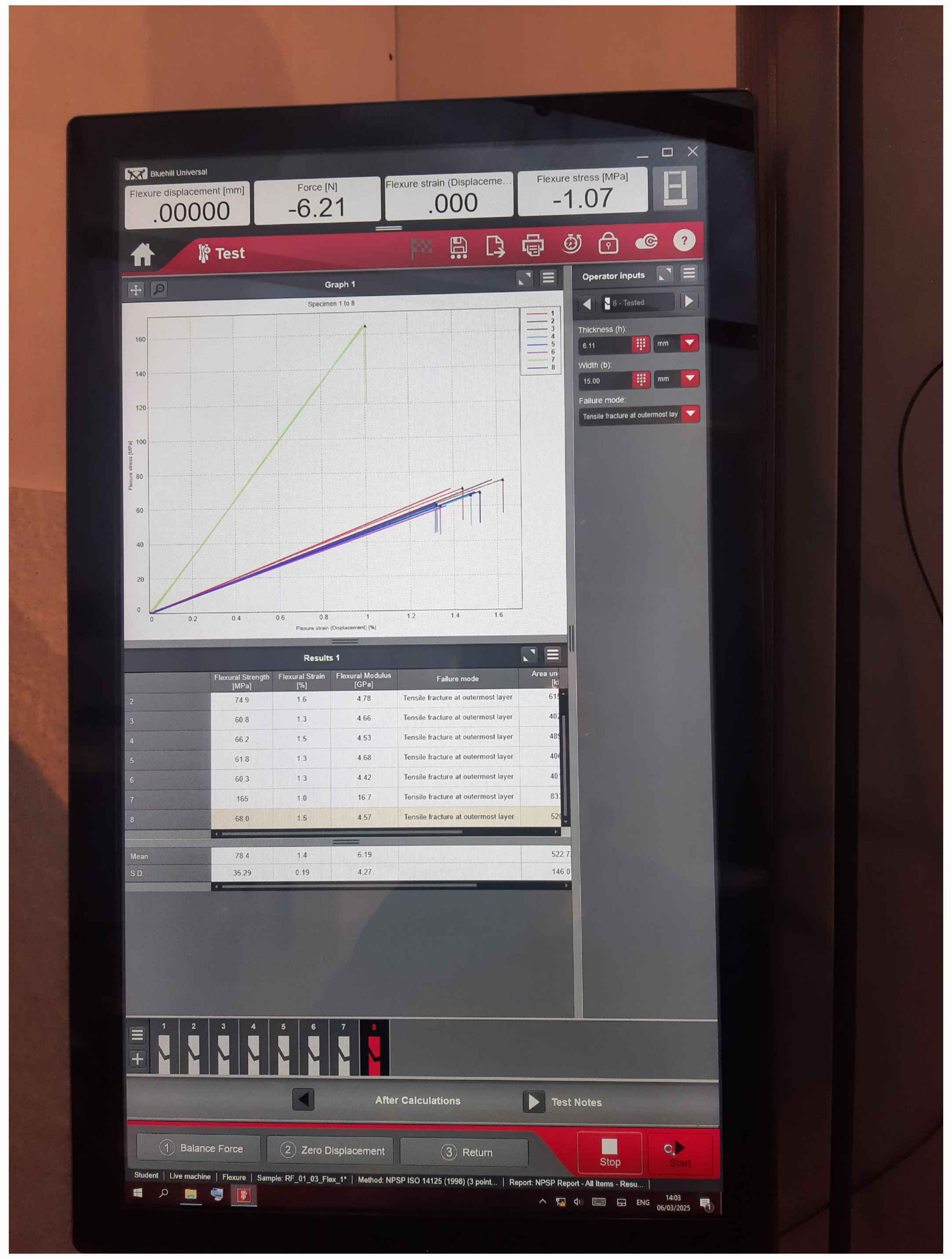


Bulk density test



Microscopic analysis

Testing process

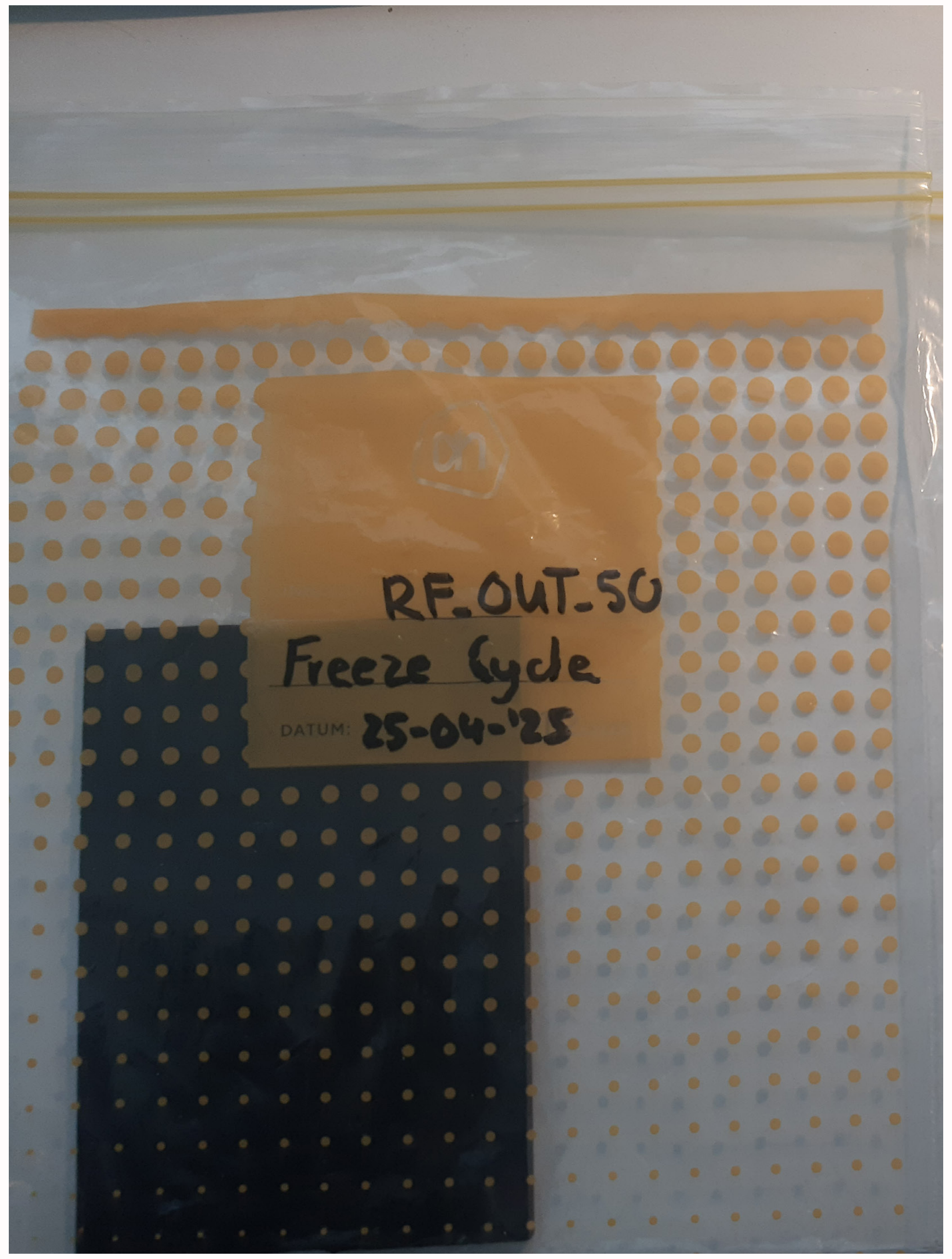


3 point bending (ISO 14125A)

Charpy Impact test (ISO 179)

Testing process

QUV weathering machine (Time: 3 weeks)



Frost resistance (Time intervals: 8h x 8h x 10 cycles)

Testing process

Watersubmersion (Time intervals: 24h x 28 days)

Comparison results

Flexural strength

Impact resistance

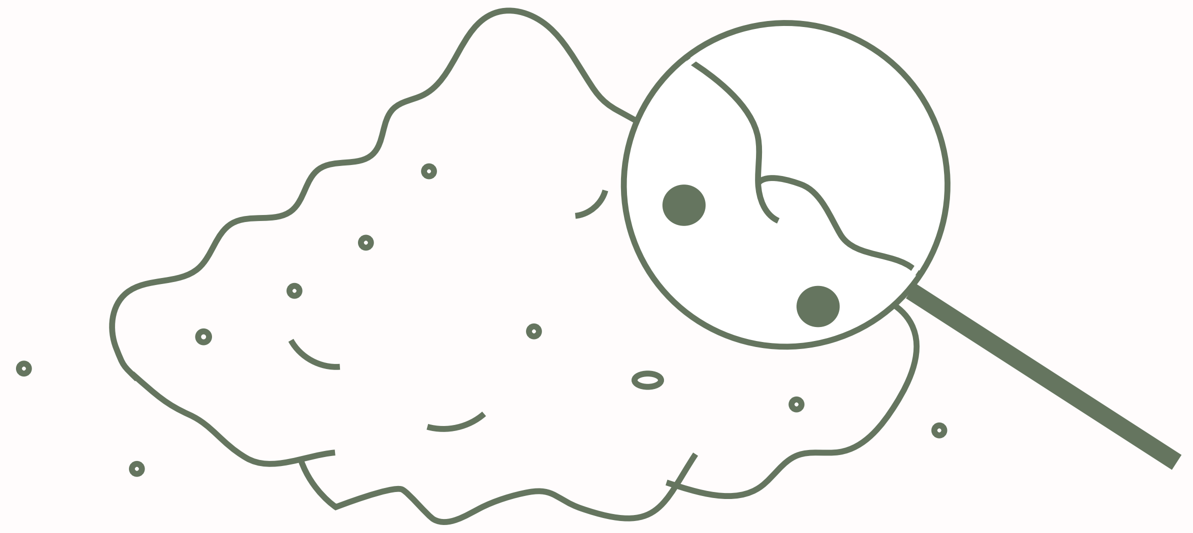
Durability

Workability

Evaluation scale	Strength (MPa)	2. Impact Resistance (kJ/m^2)	3. Workability	4. Durability
	Scale 0-80	**Scale 1-6**	**Scale 0-5**	**Scale 0-5**
	0 = 0-16	0 = 1-2	0 = liquid not workable	0 = total destruction
	1 = 17-32	1 = 2-3	1 = thick liquid	1= cracks and all of above
	2 = 33-48	2 = 3-4	2 = super sticky	2= deformation
	3 = 49-64	3 = 4-5	3 = sticky	3= visual change (coloration)
	4 = 65-80	4 = 5-6	4 = thick crumble (a bit sticky)	4= minimal visual change
	5= 80	5= 6	5 = crumble	5= no visual change

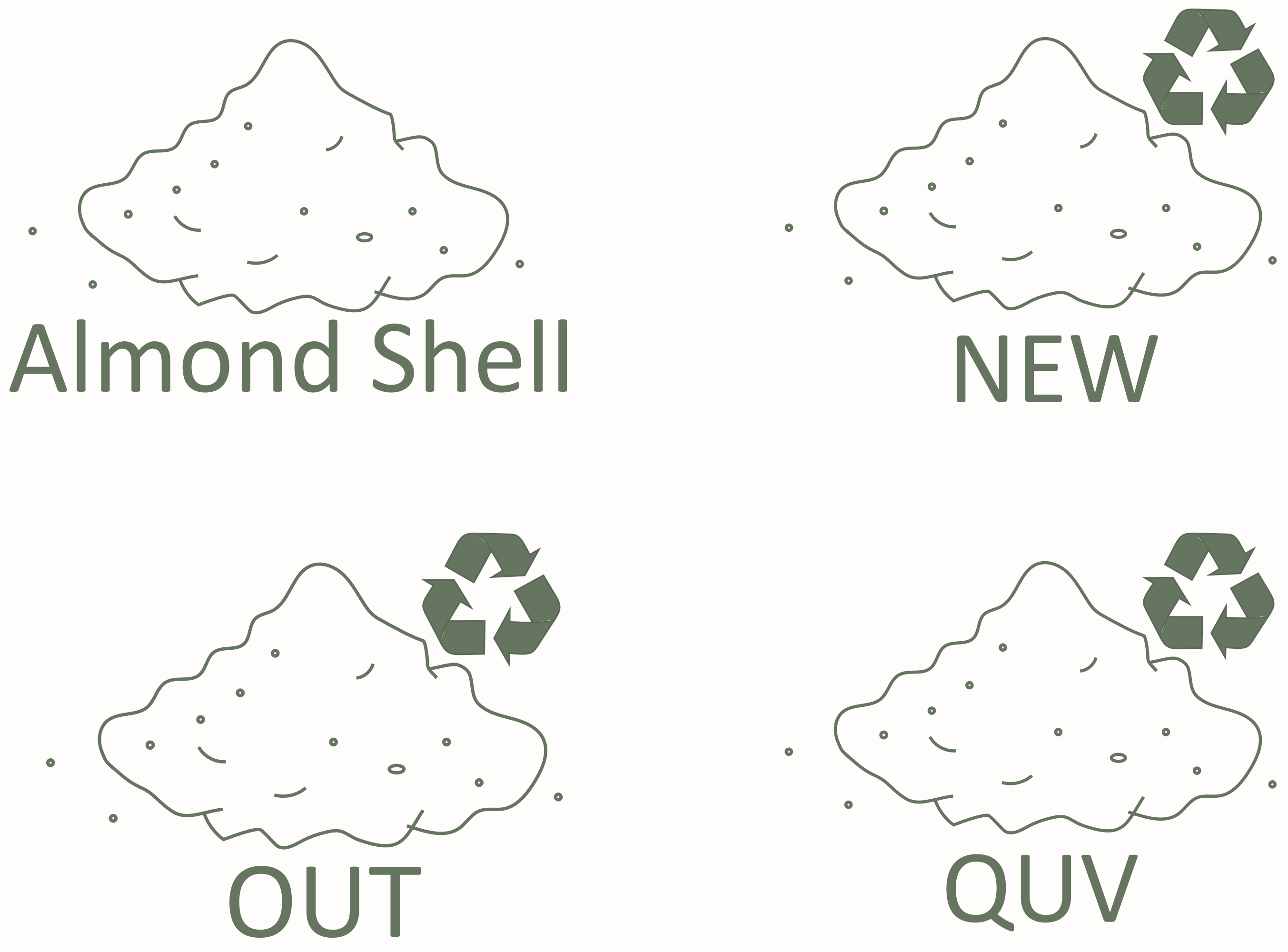
Results testing phases

PHASE 1

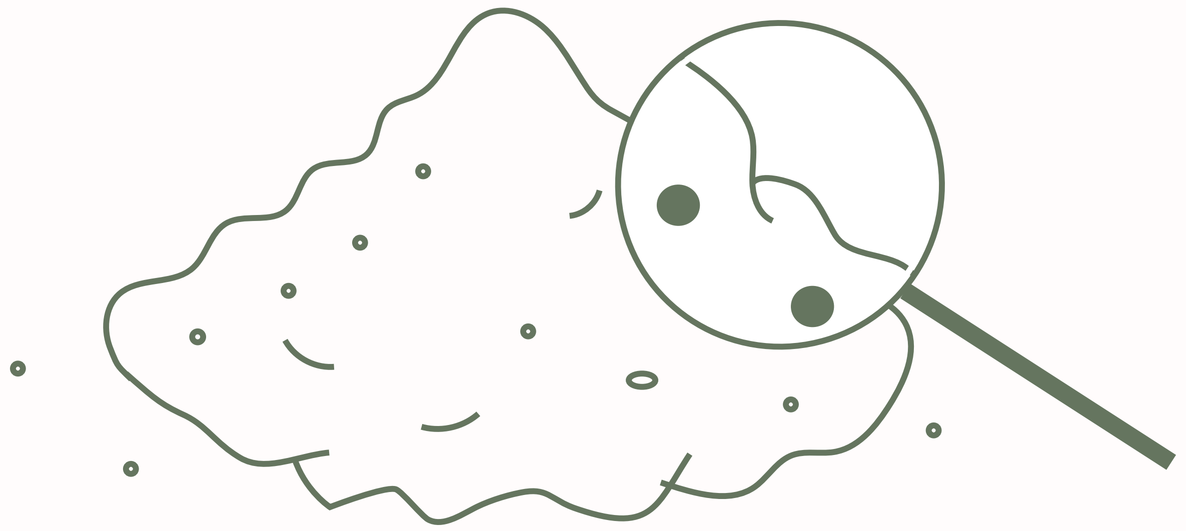


Filler analysis:

- Bulk Density
- Microscopic analysis



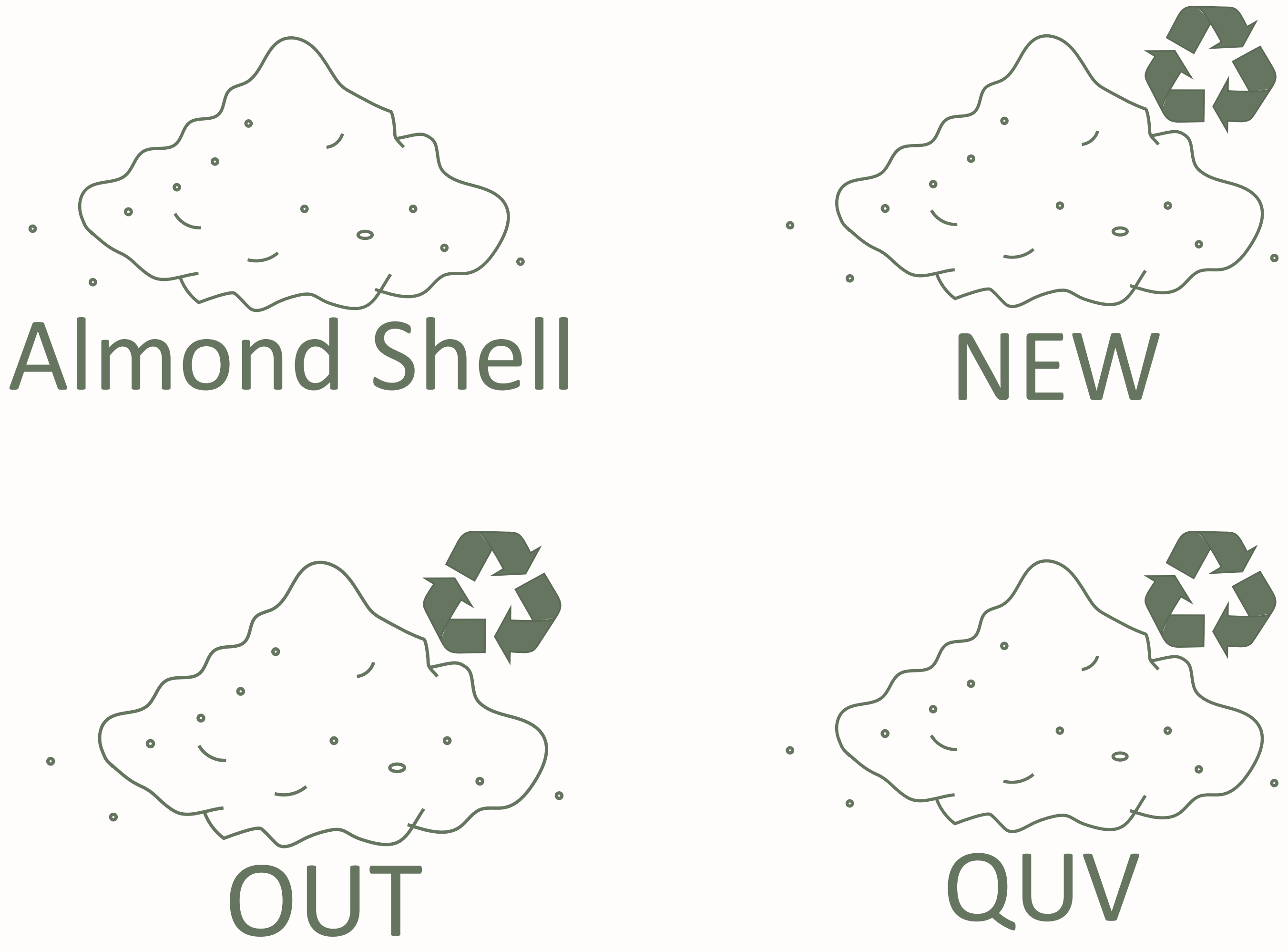
PHASE 1



Bulk Density

$$Density\ [kg/m^3] = W / V_f$$

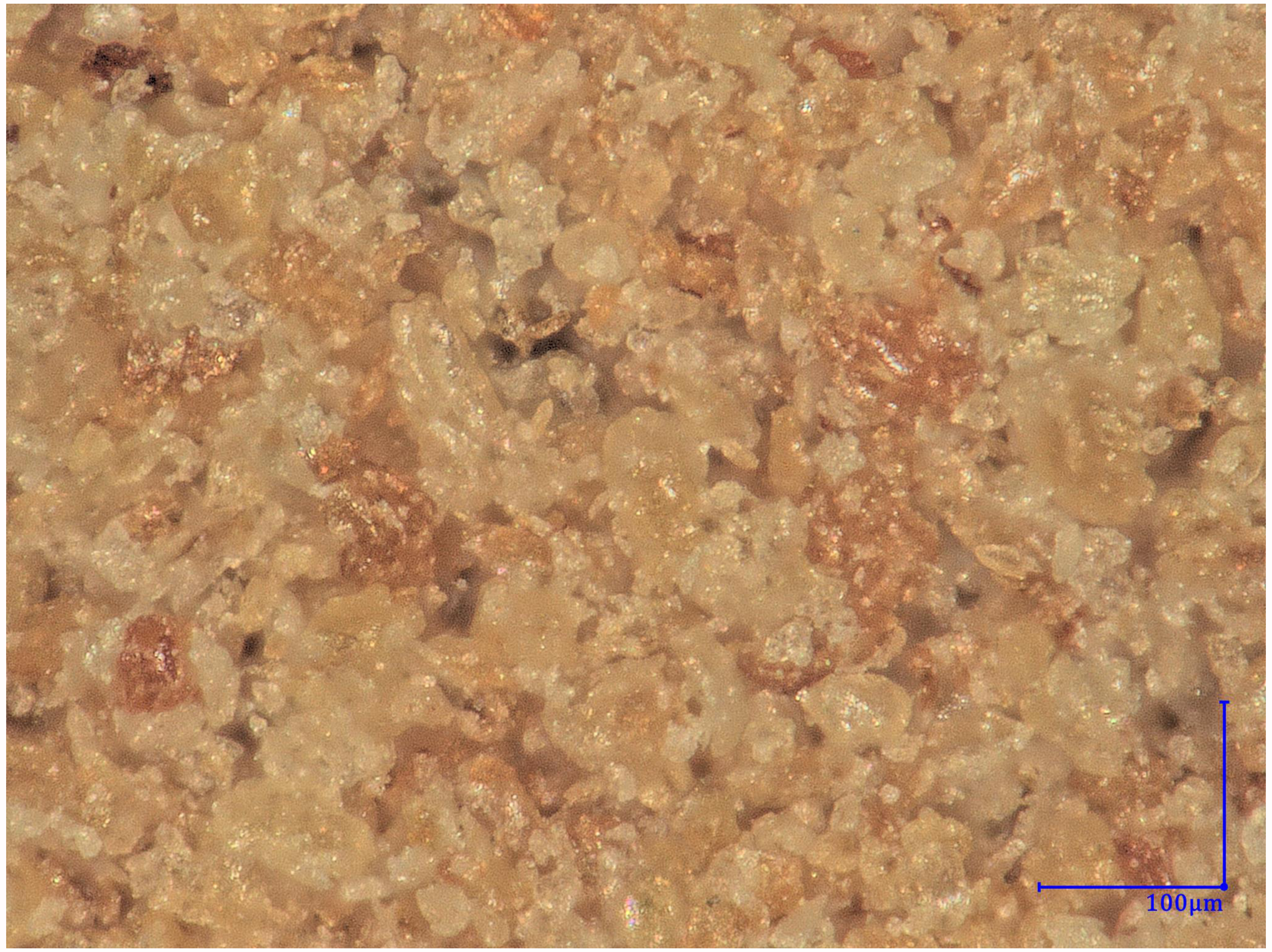
V_f: *Volume filler*



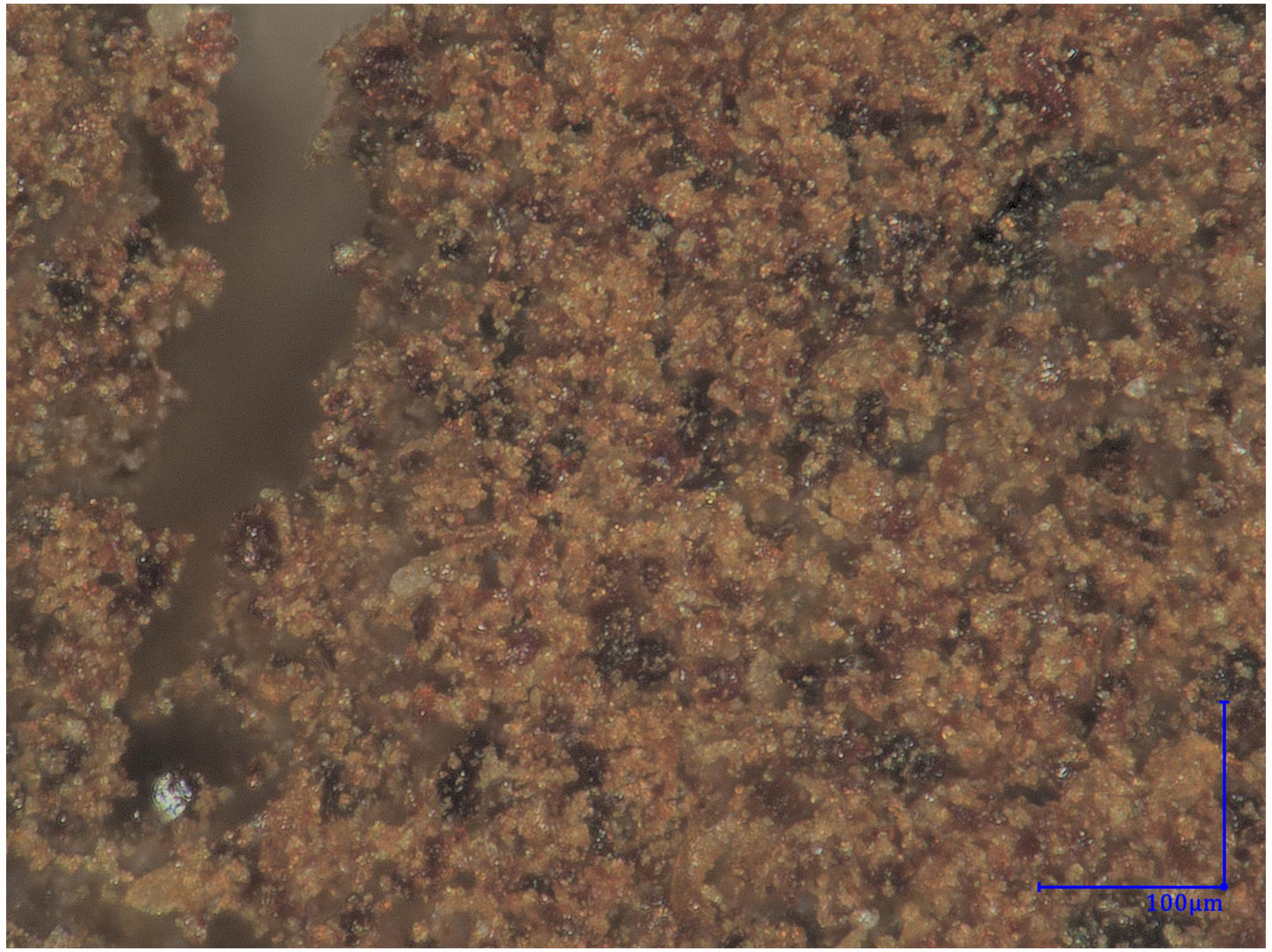
Filler type	Av. Bluk Density [kg/m3]
Almond shell filler	666
Recycled filler NEW	609
Recycled filler OUT	589
Recycled filler QUV	450

PHASE 1

Different grains size & shapes



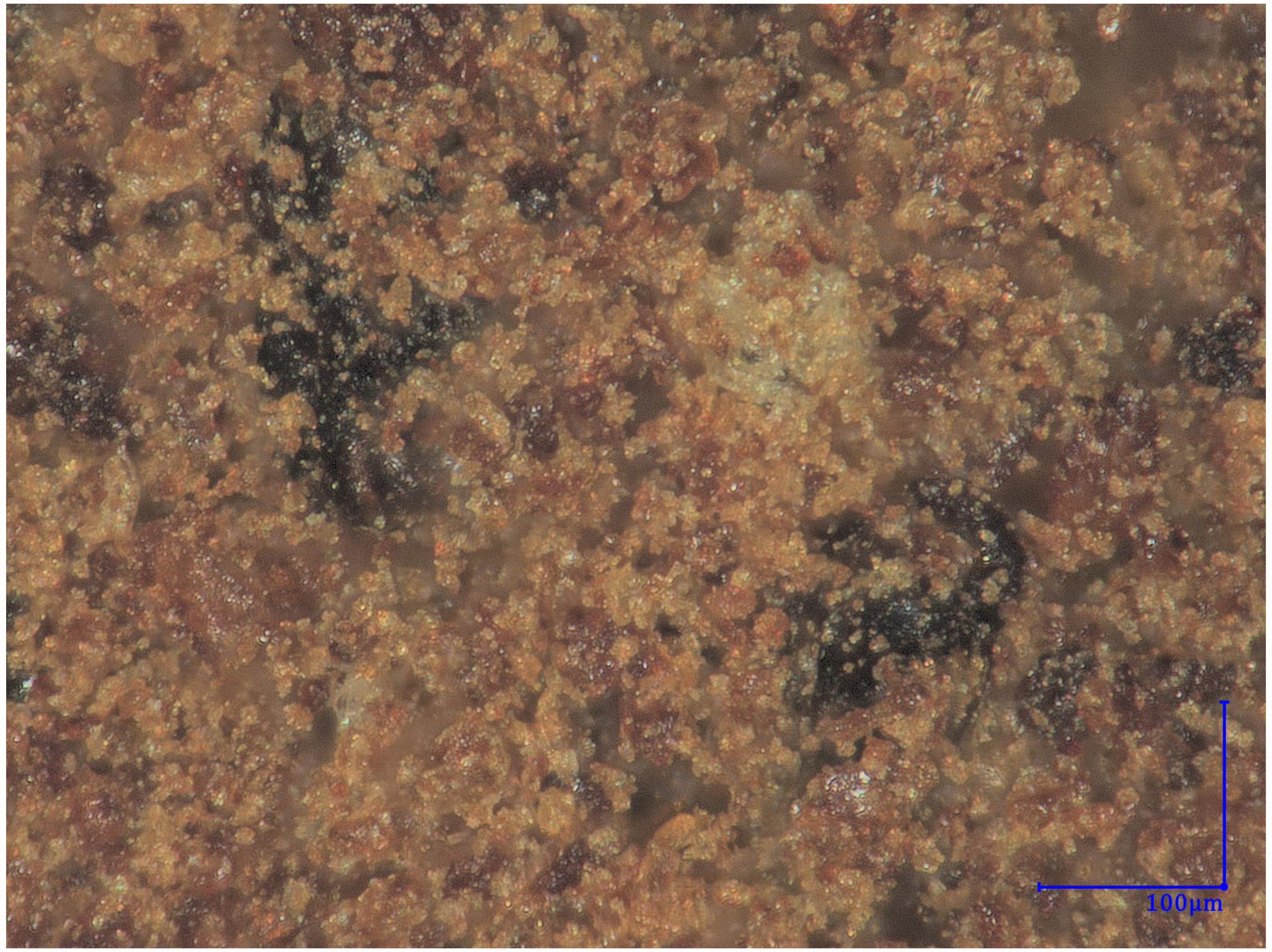
Almond shell filler, < 80 µm



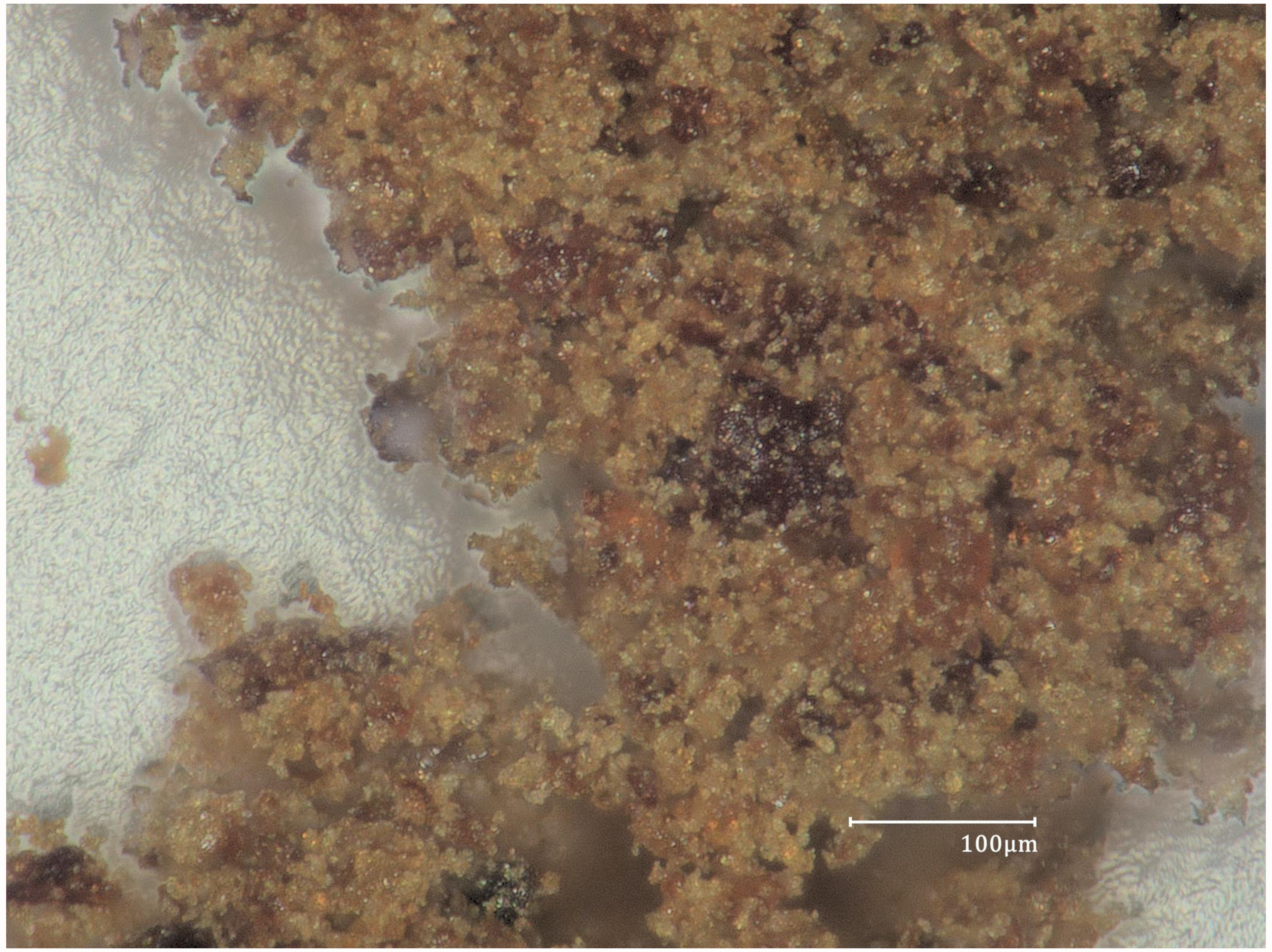
Recycled filler NEW, < 50 µm

PHASE 1

Different grains and size compositon

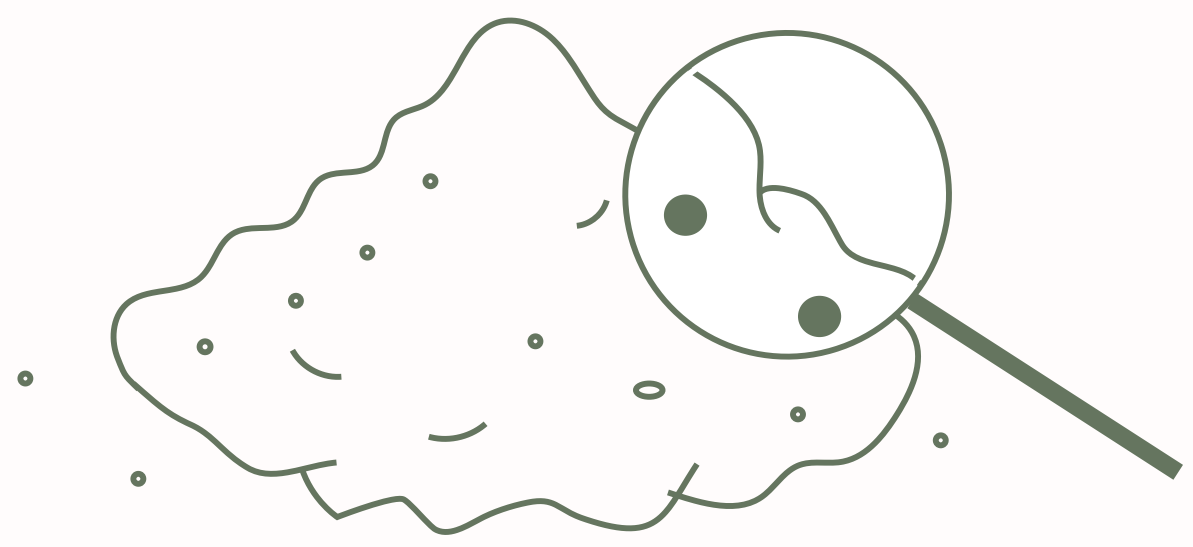


Recycled filler OUT, < 50 μm



Recycled filler QUV, < 50 μm

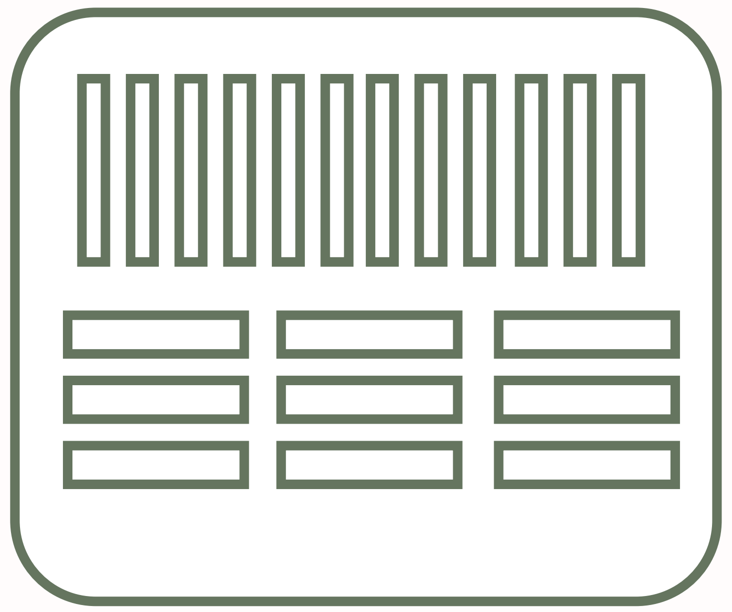
PHASE 1



Findings:

- Lower density
- Grain size
- Higher surface area
- Non-Homogenous

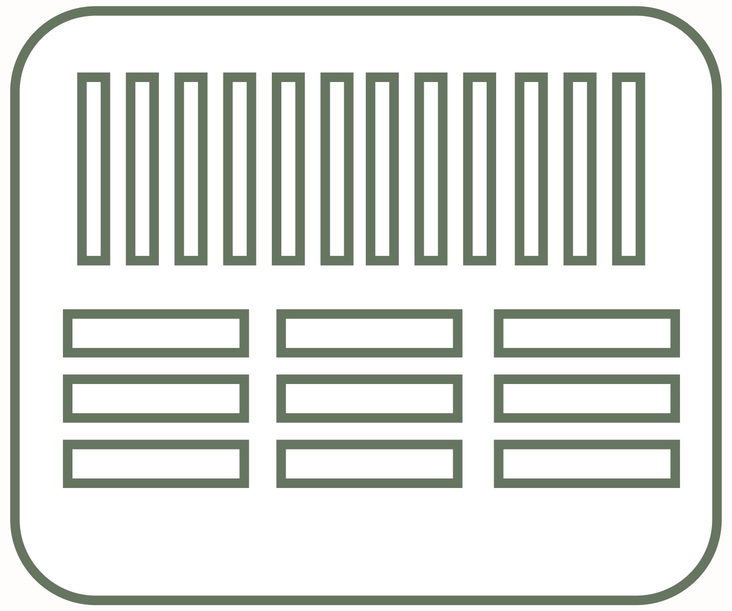
PHASE 2



"RF_NEW_50"

Filler type — State of recycling — Filler load (w%)

PHASE 2A



Materials sample testing

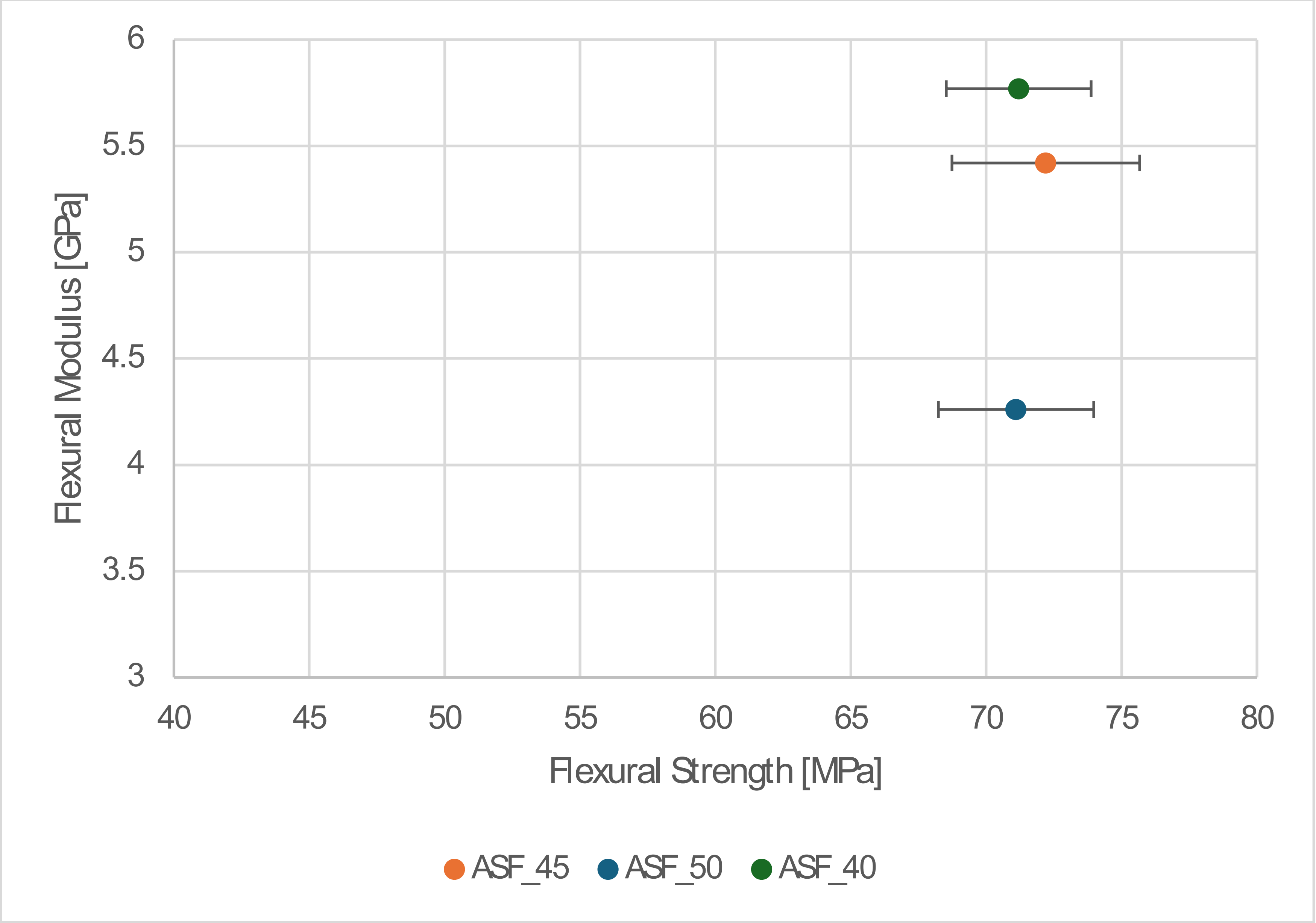
- Flexural strength
- Impact resistance
- Workablity
- Durability

PHASE 2A

Flexural testing
Almond shell filler - ASF

- ASF_40
- ASF_45
- ASF_50

Name sample	Flexural strength (Mpa)	Flexural modulus (Gpa)	flexural strain	fk (Mpa)
ASF_40	71.2	5.77	1.3	62.46
ASF_45	72.2	5.42	1.3	60.82
ASF_50	71.1	4.26	1.2	61.70



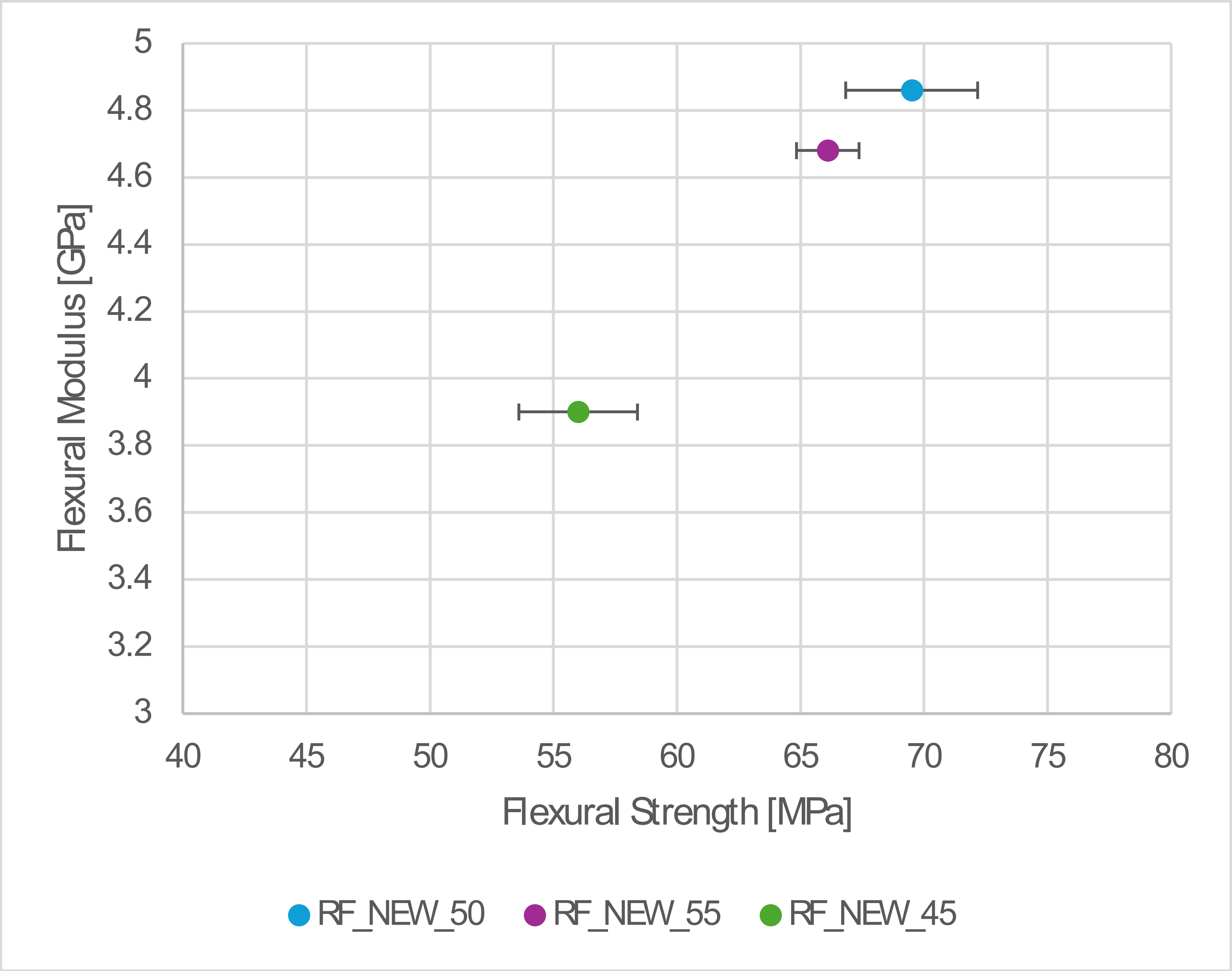
Almond Shell

PHASE 2A

Flexural testing
Recycled filler NEW - RF_NEW

- RF_NEW_45
- RF_NEW_50
- RF_NEW_55

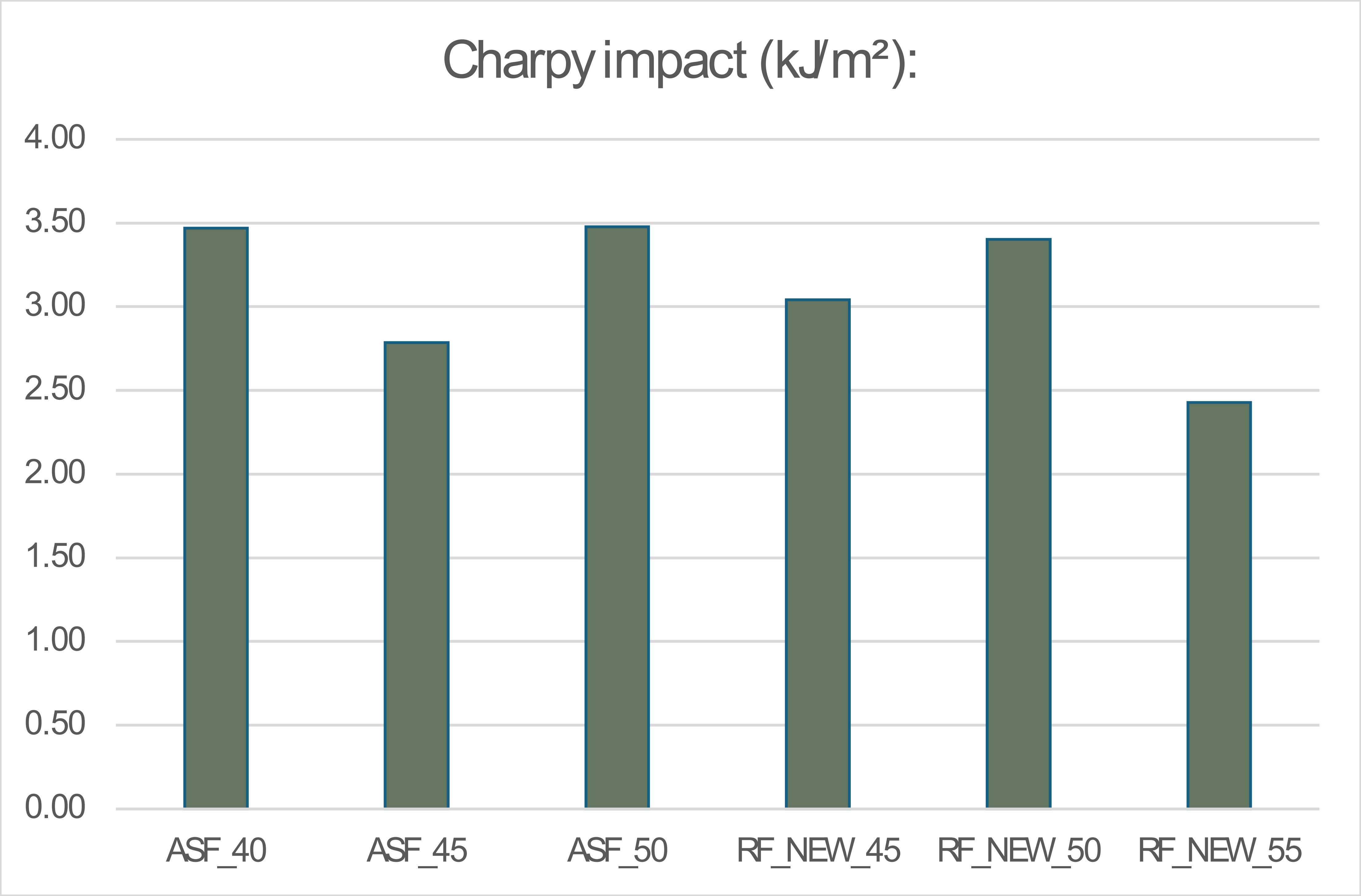
Name sample	Flexural strength (Mpa)	Flexural modulus (Gpa)	flexural strain	fk (Mpa)
RF_NEW_45	56	3.9	1.5	48.13
RF_NEW_50	69.5	4.86	1.5	60.74
RF_NEW_55	66.1	4.68	1.4	57.16



NEW

PHASE 2A

Impact resistance



NEW

Almond Shell

PHASE 2A

Workability

ASF_45

ASF_50

RF_NEW_45

RF_NEW_50

Almond shell filler

Recycled filler NEW

PHASE 2A

Durability

- ASF_45

Reference

QUV

- RF_NEW_50

Reference

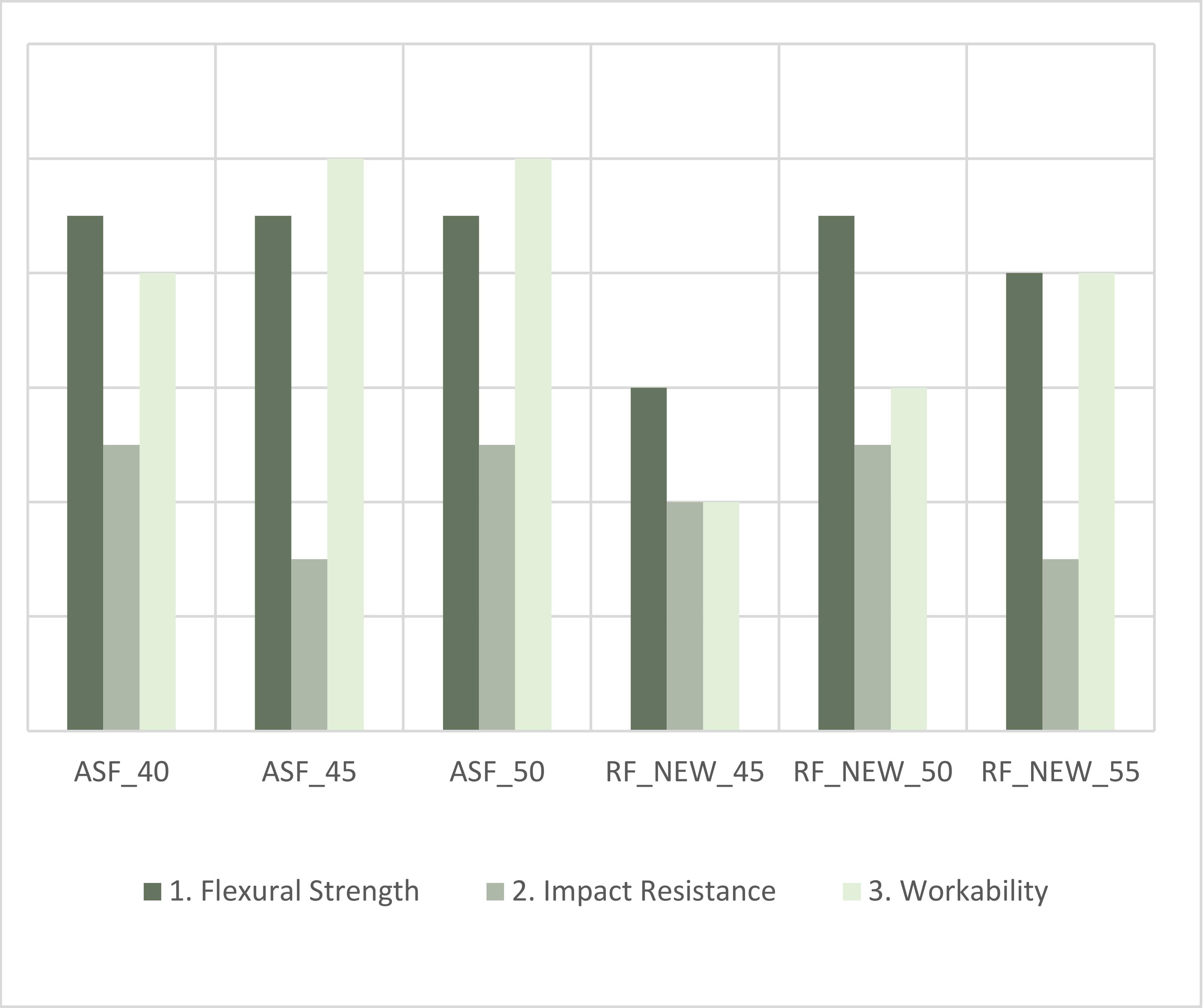
QUV

PHASE 2A

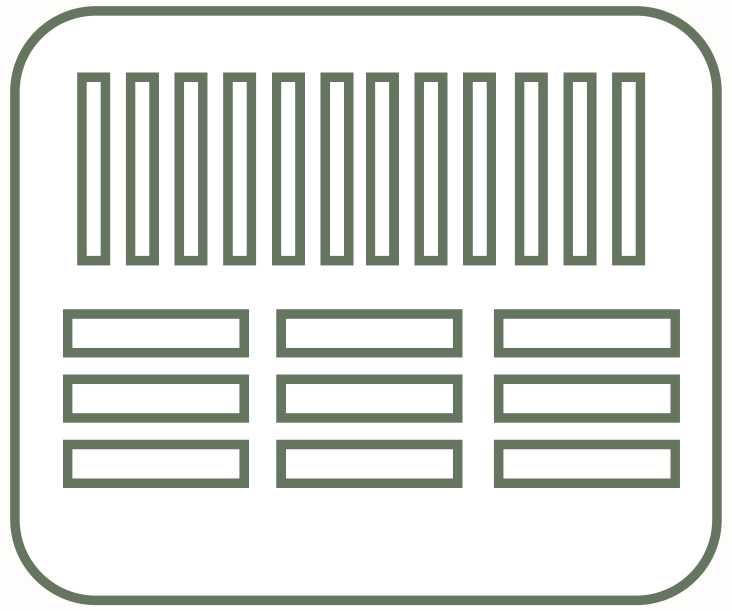
Findings

Recycled fillers

Name sample	Flexural strength (Mpa)	Flexural modulus (Gpa)	flexural strain	fk (Mpa)
ASF_40	71.2	5.77	1.3	62.46
ASF_45	72.2	5.42	1.3	60.82
ASF_50	71.1	4.26	1.2	61.70
RF_NEW_45	56	3.9	1.5	48.13
RF_NEW_50	69.5	4.86	1.5	60.74
RF_NEW_55	66.1	4.68	1.4	57.16

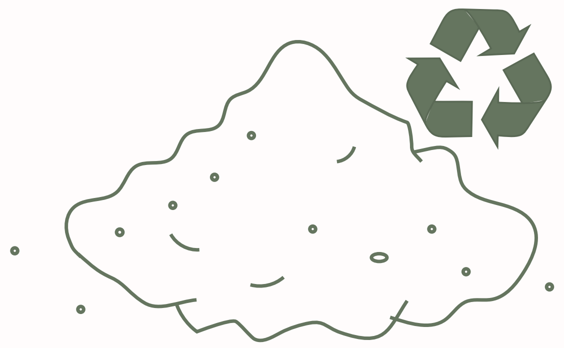


PHASE 2B

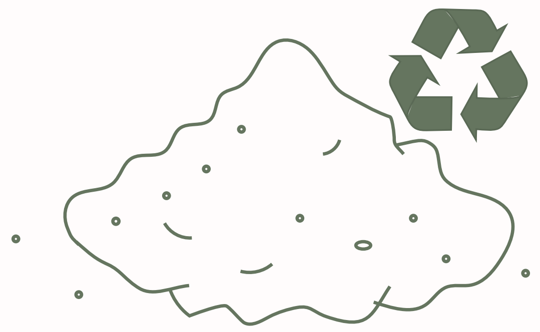


Materials sample testing

- Flexural strength
- Impact resistance
- Workablity
- Durability

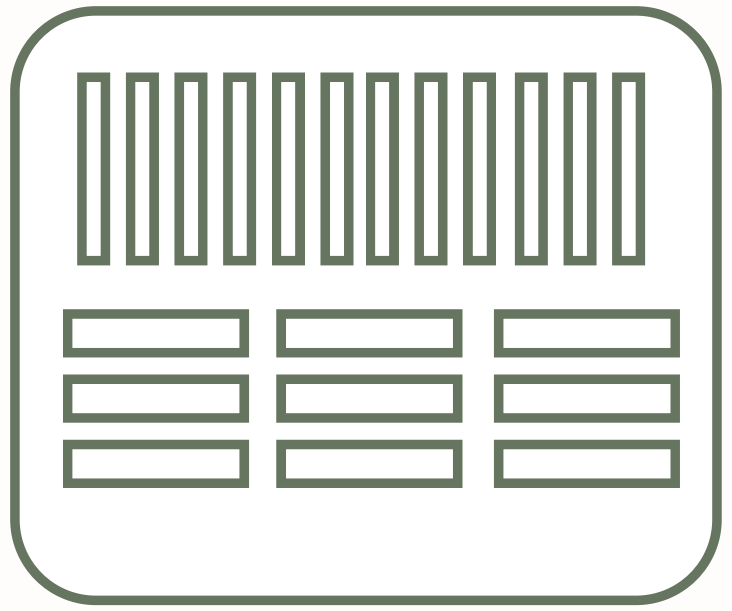


OUT



QUV

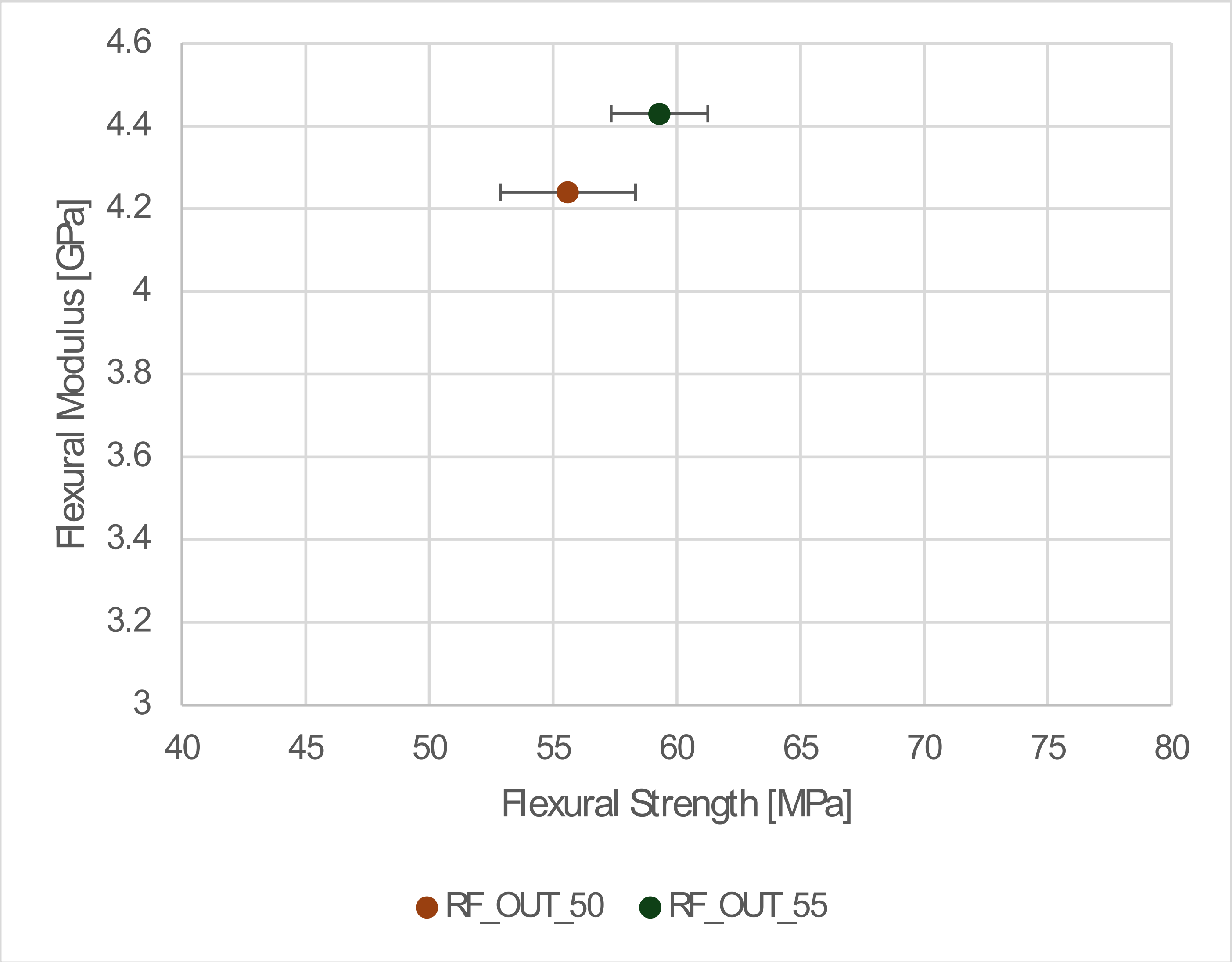
PHASE 2B

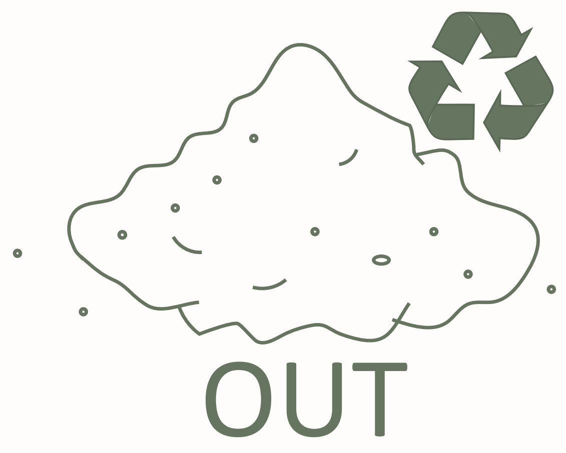


Flexural strength
Recycled filler OUT - RF_OUT

- RF_OUT_50
- RF_OUT_55

Name sample	Flexural strength (Mpa)	Flexural modulus (Gpa)	flexural strain	fk (Mpa)
RF_OUT_50	55.6	4.24	1.3	44.02
RF_OUT_55	59.3	4.43	1.4	52.92



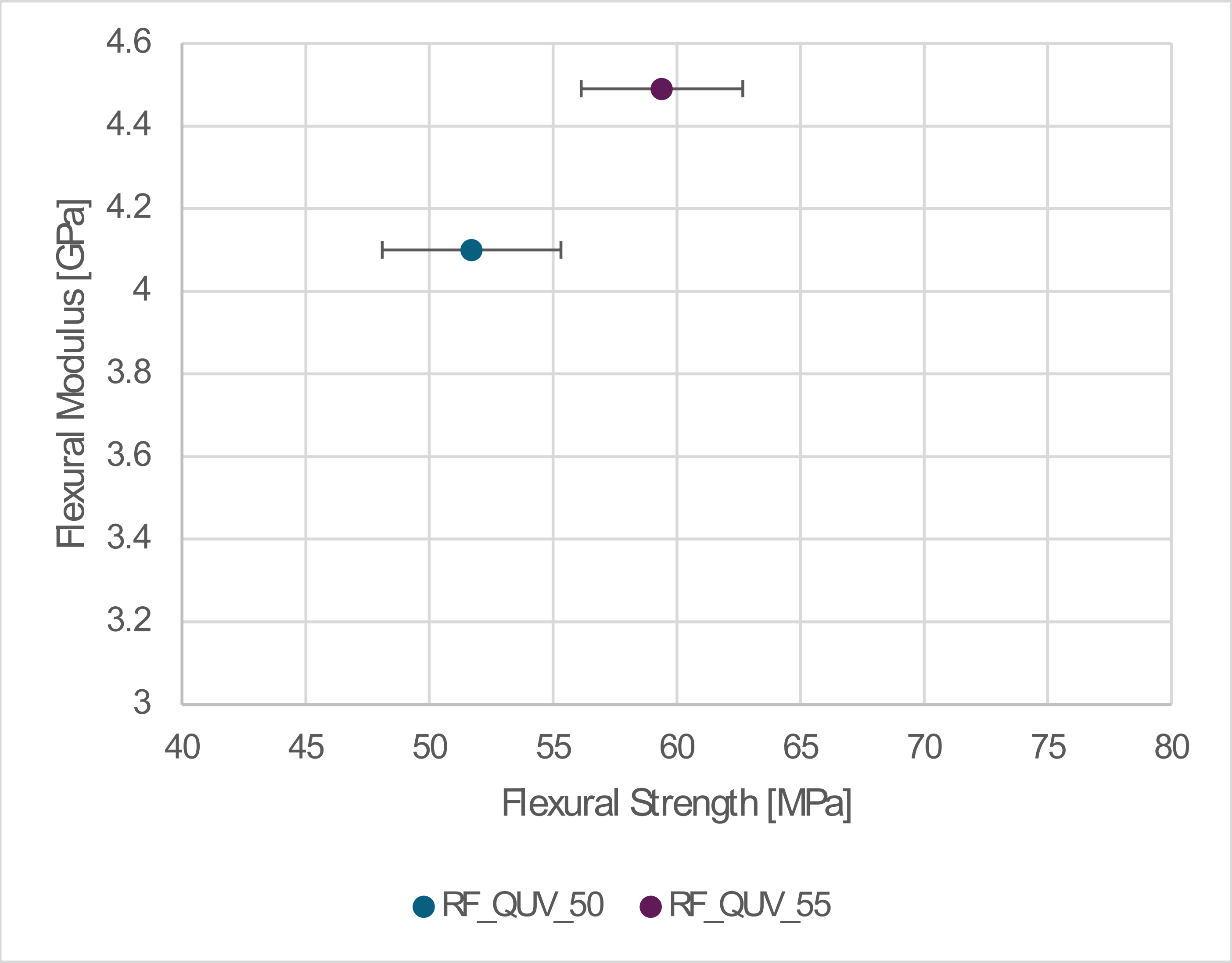


PHASE 2B

Flexural strength
Recycled filler QUV - RF_QUV

- RF_QUV_50
- RF_QUV_55

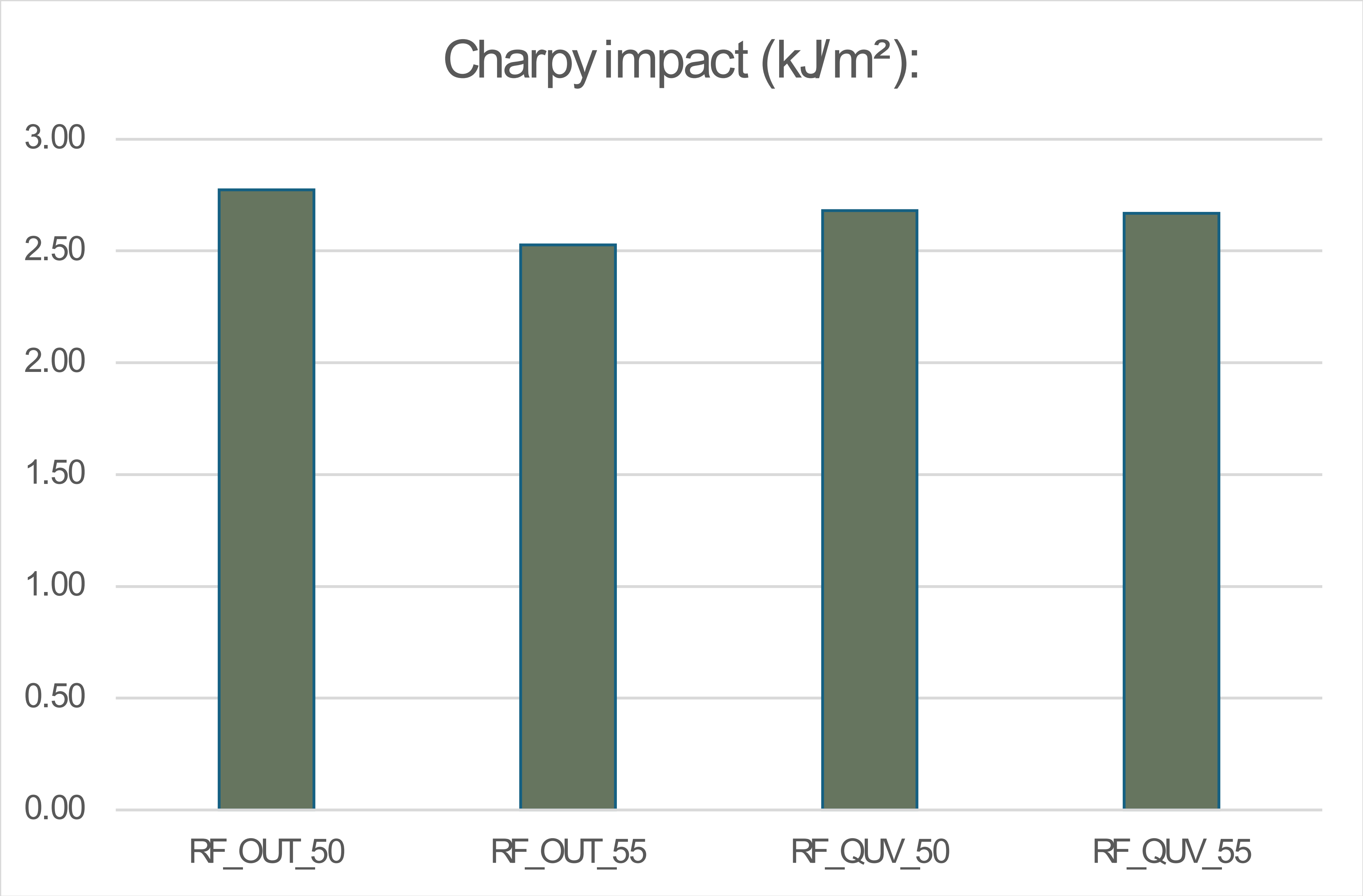
Name sample	Flexural strength (Mpa)	Flexural modulus (Gpa)	flexural strain	fk (Mpa)
RF_QUV_50	51.7	4.1	1.4	47.96
RF_QUV_55	59.4	4.49	1.4	55.73

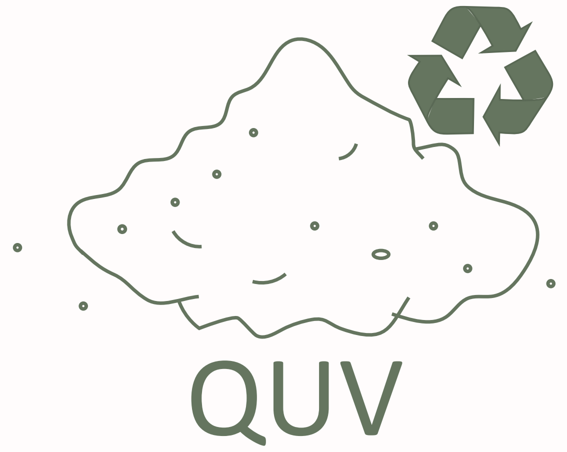


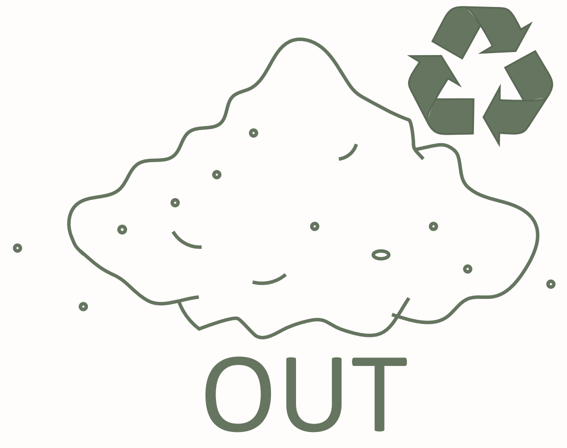
QUV

PHASE 2B

Impact resistance
Recycled filler OUT - RF_OUT







PHASE 2B

Workability
Recycled filler OUT - RF_OUT

RF_OUT_50

RF_OUT_55

OUT

PHASE 2B

Durability
Recycled filler OUT - RF_OUT

- RF_OUT_50

Reference

QUV

- RF_OUT_55

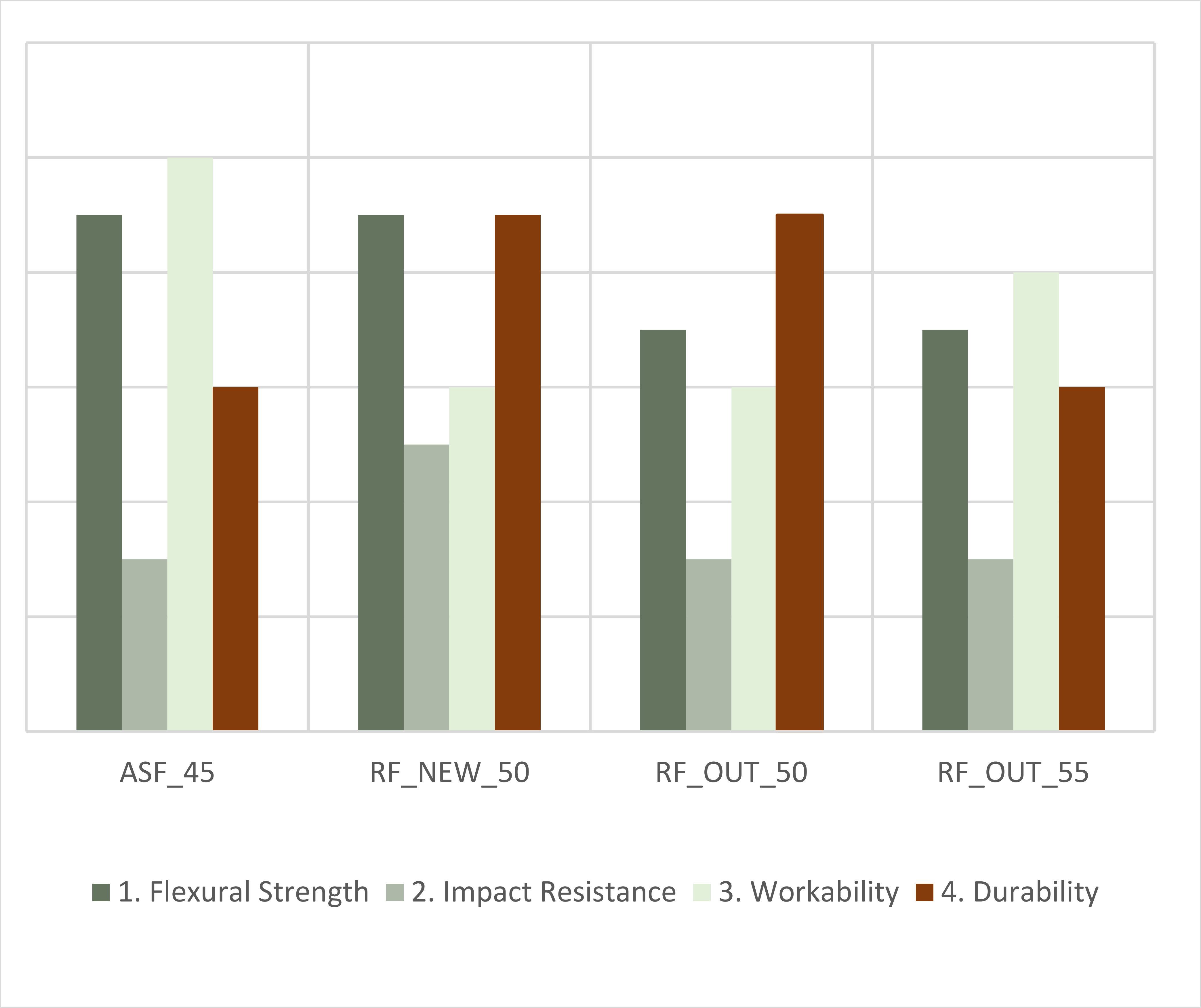
Reference

QUV

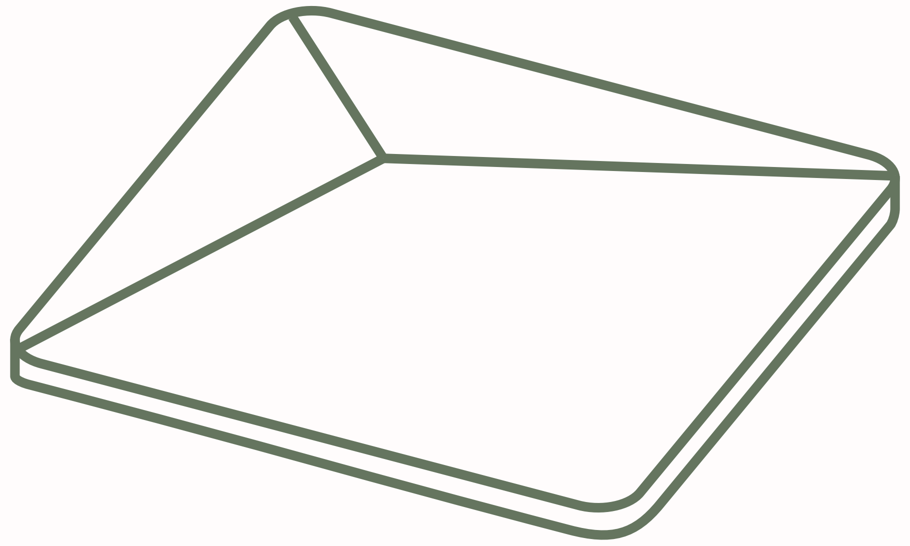
PHASE 2

Findings

- Lower mechanical properties
- Similar impact resistance
- Higher durability
- Lower workability
- Overall score

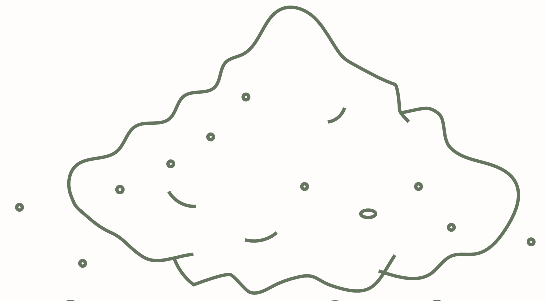


PHASE 3

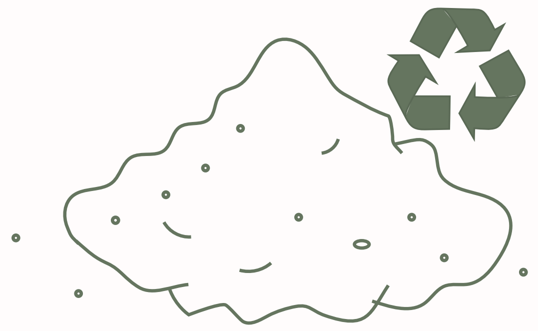


3D moulding

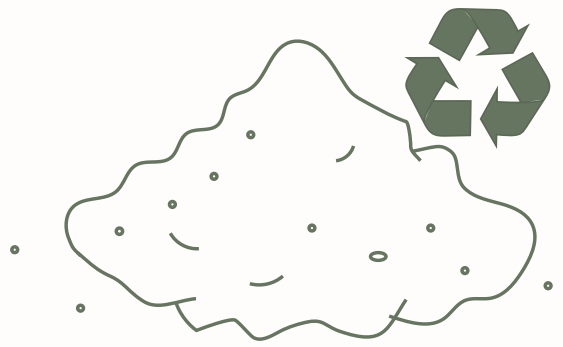
- Workability and flow
- Visual



Almond Shell

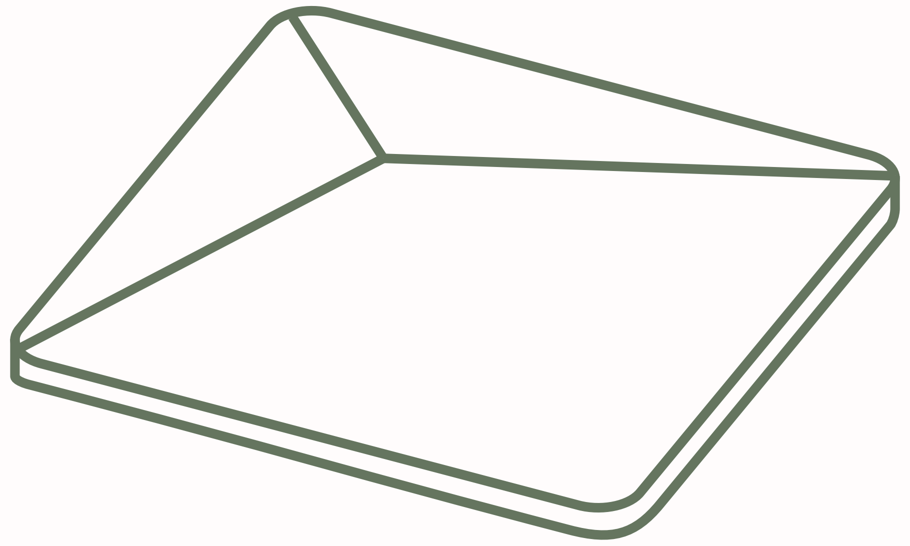


NEW



OUT

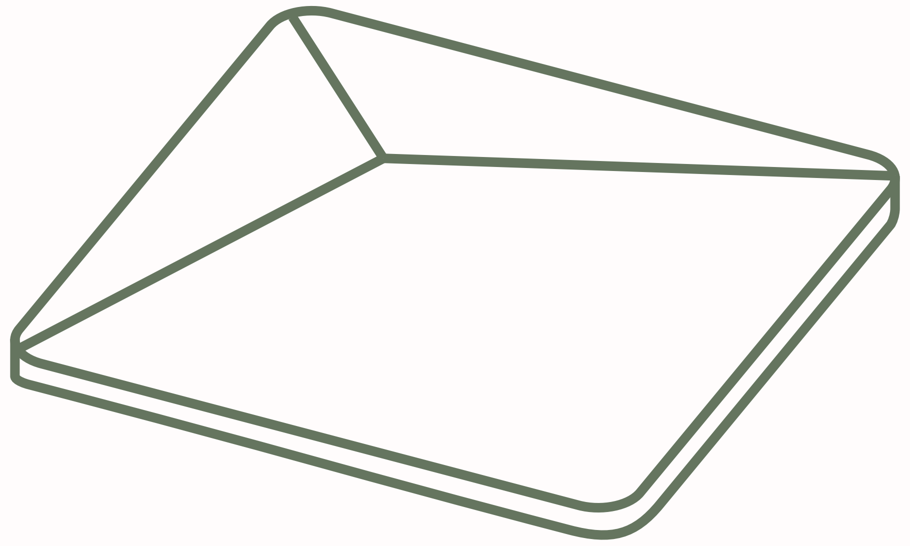
PHASE 3



Distribution first test

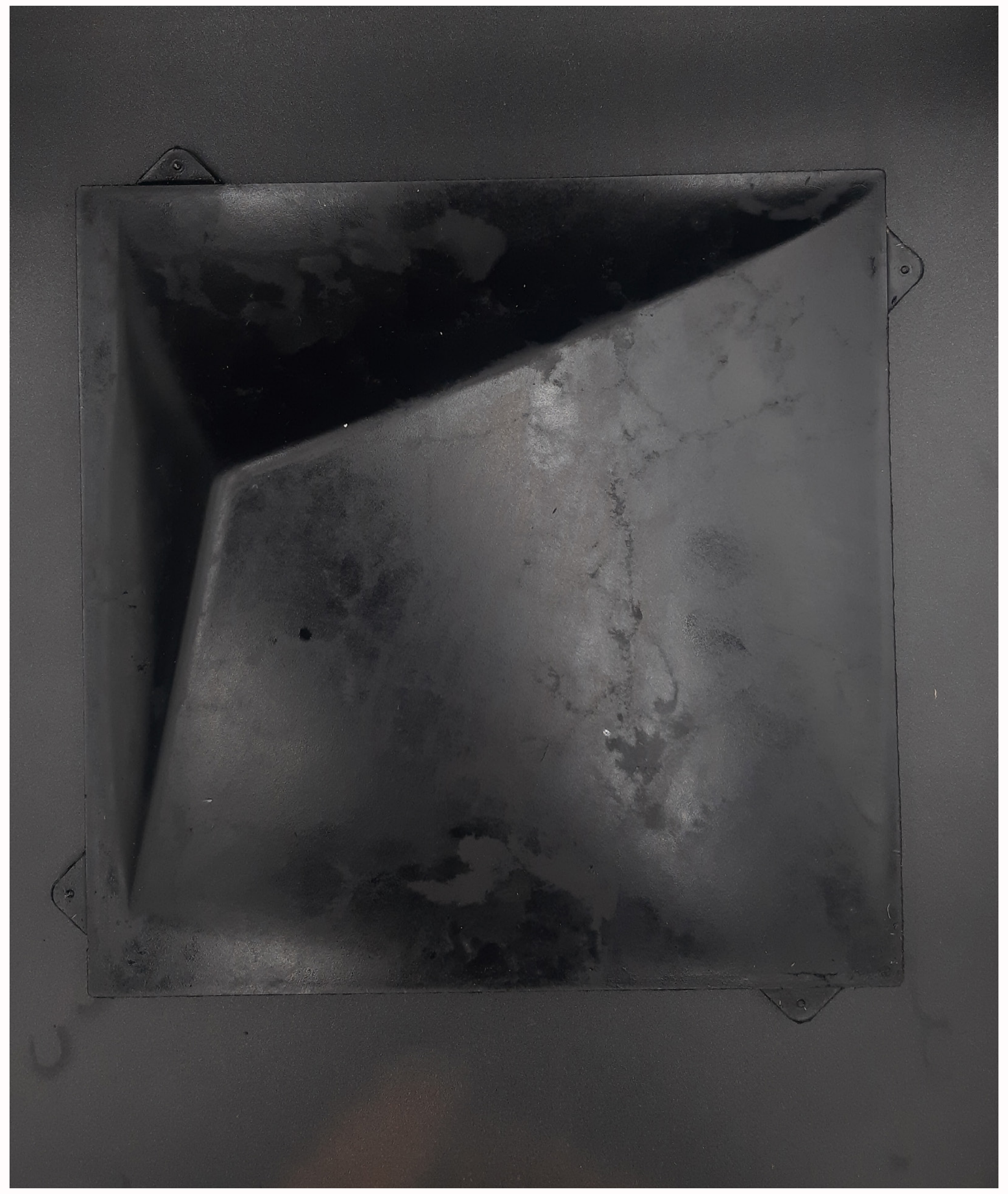
Distribution second test

PHASE 3

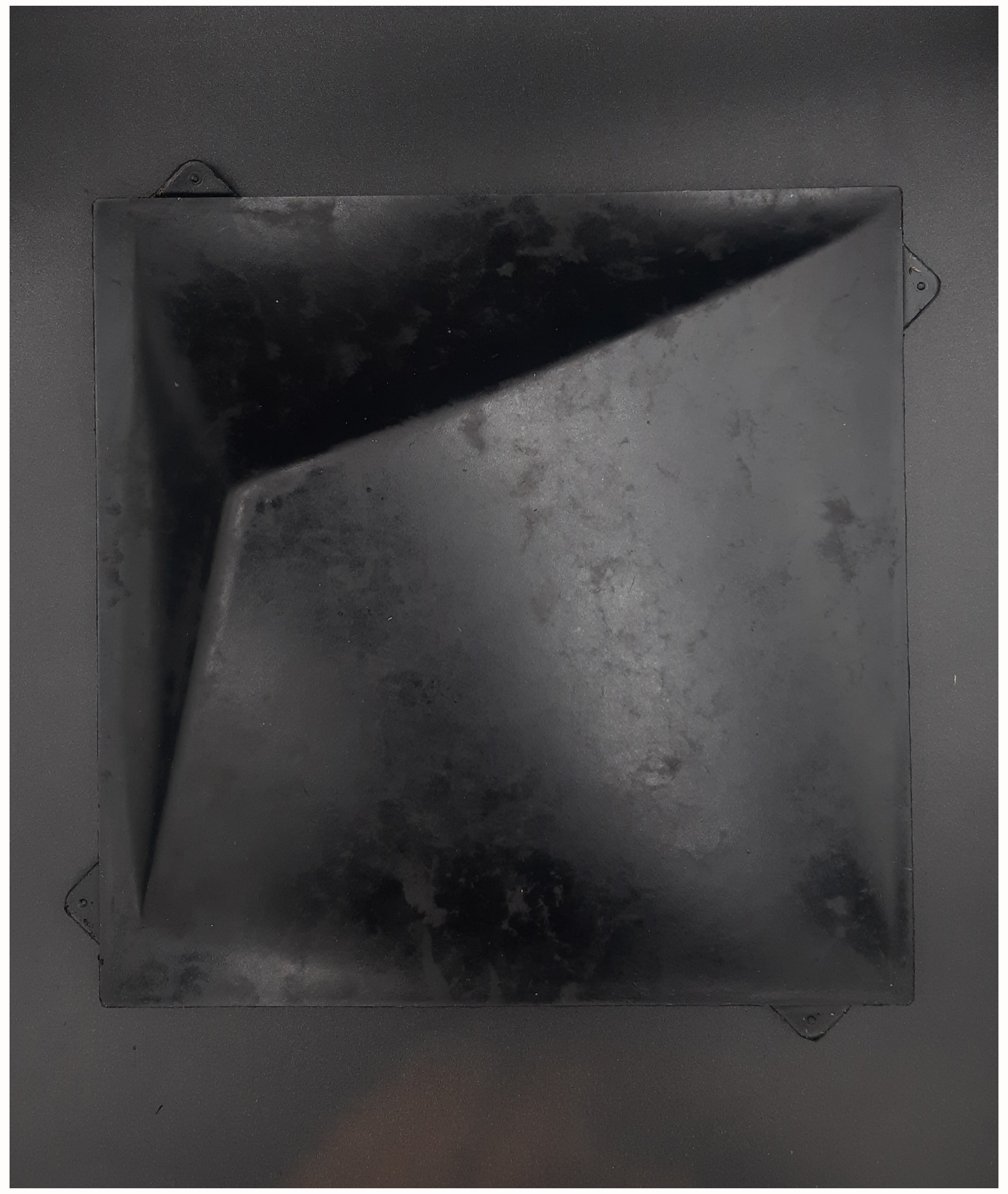


ASF_45

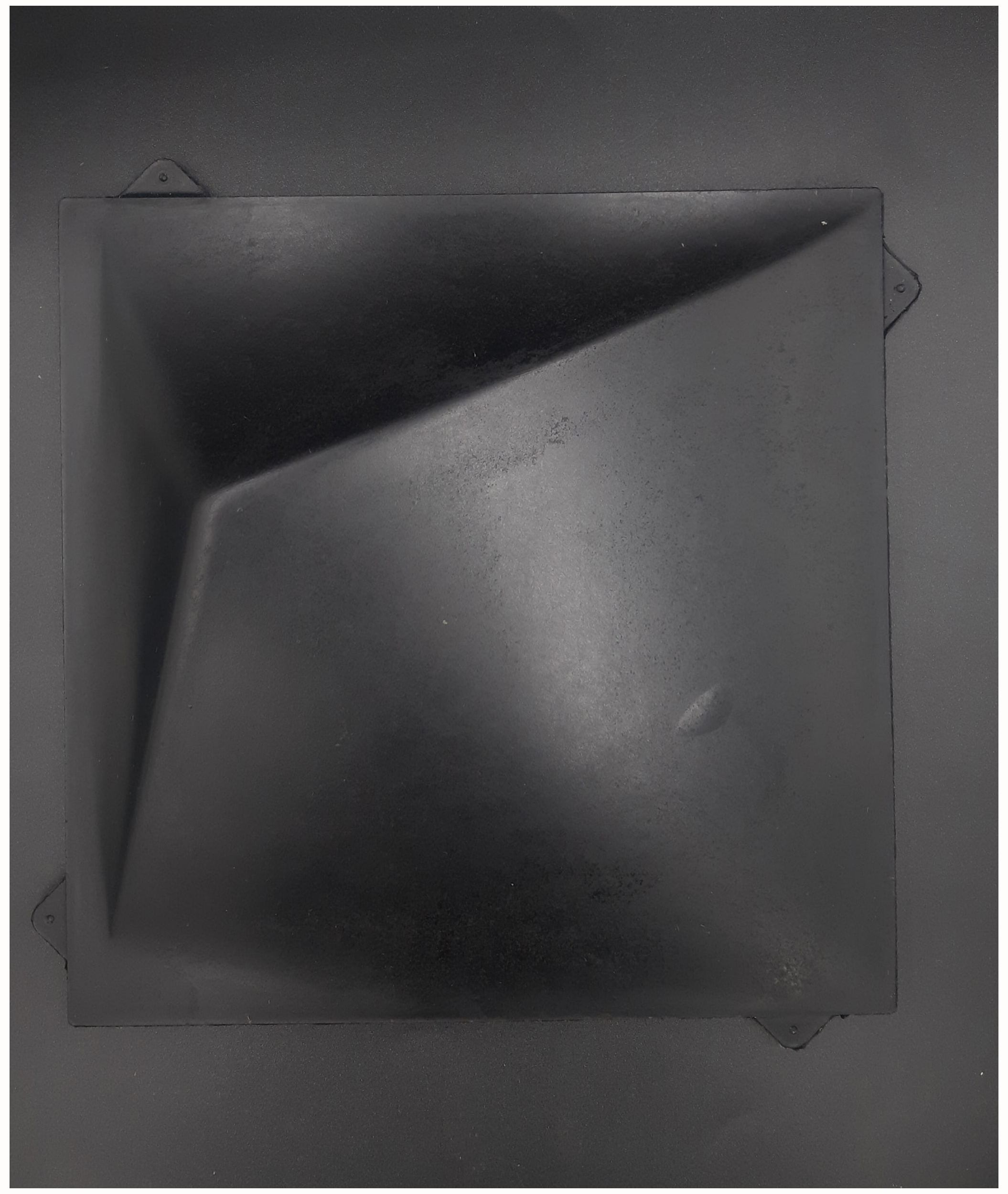
RF_NEW_50



RF_OUT_55



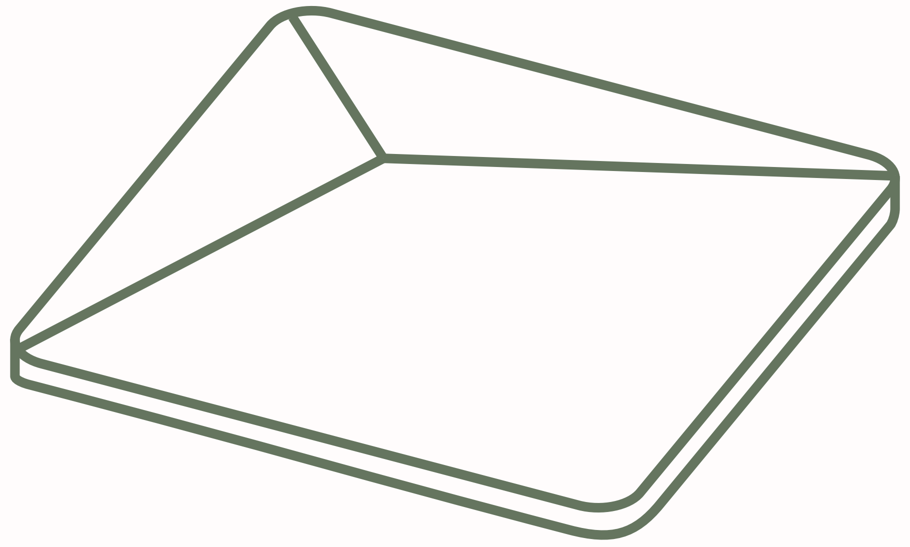
RF_OUT_50



Distribution first test

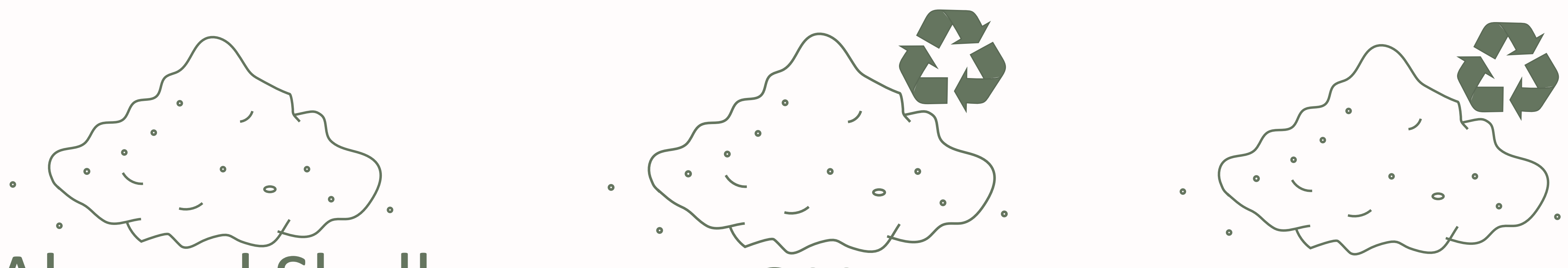
Distribution second test

PHASE 3



Findings

- Small defects
- Flow visible
- Ridges
- Surface finish



Results

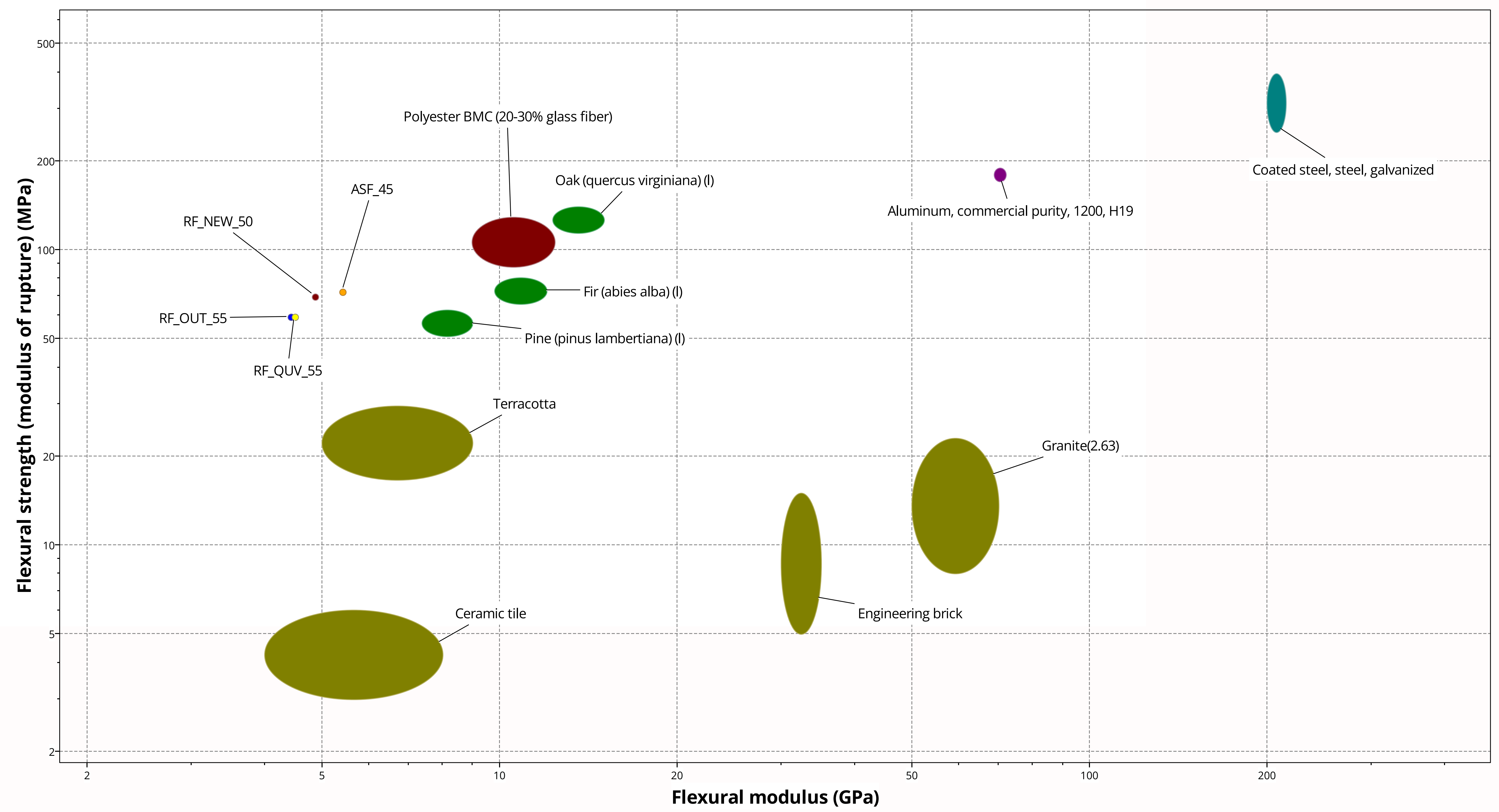
Recyclability

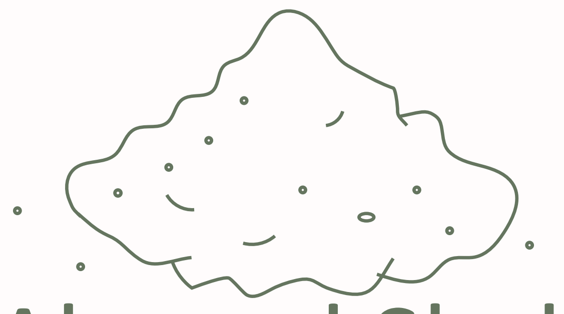
Mechanical properties

Durability

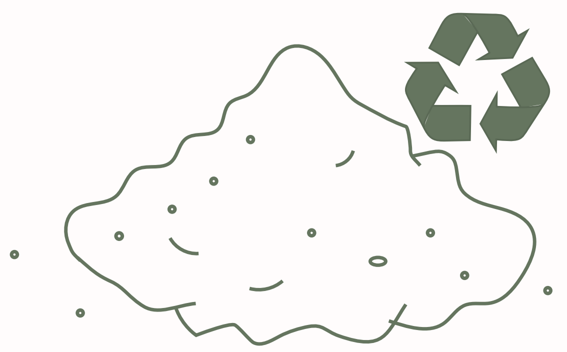
Weathering

Design freedom

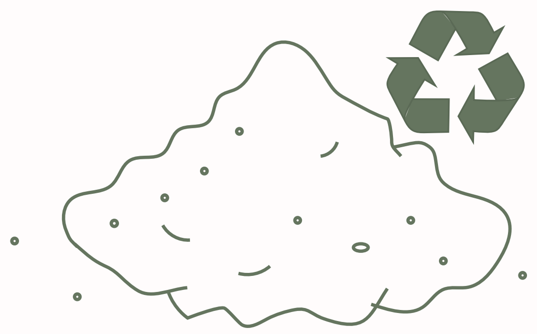




Almond Shell



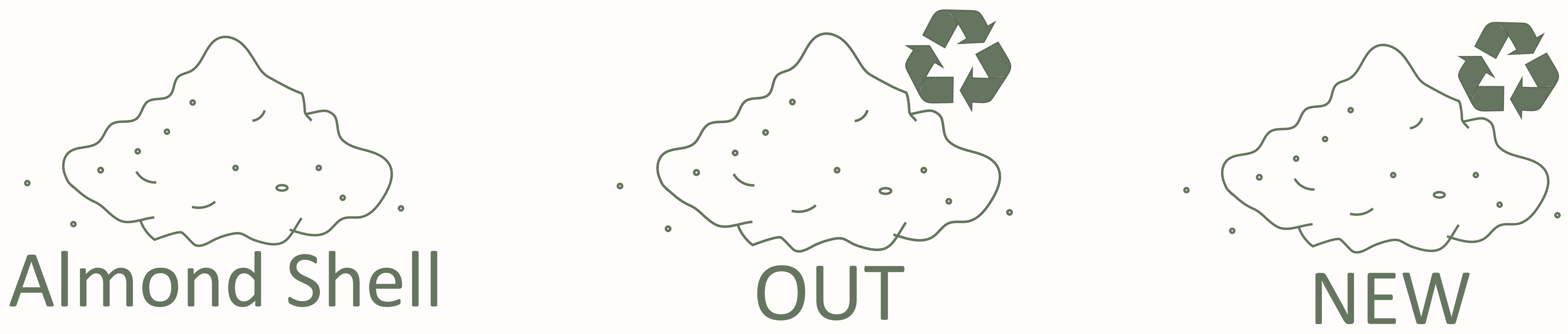
OUT



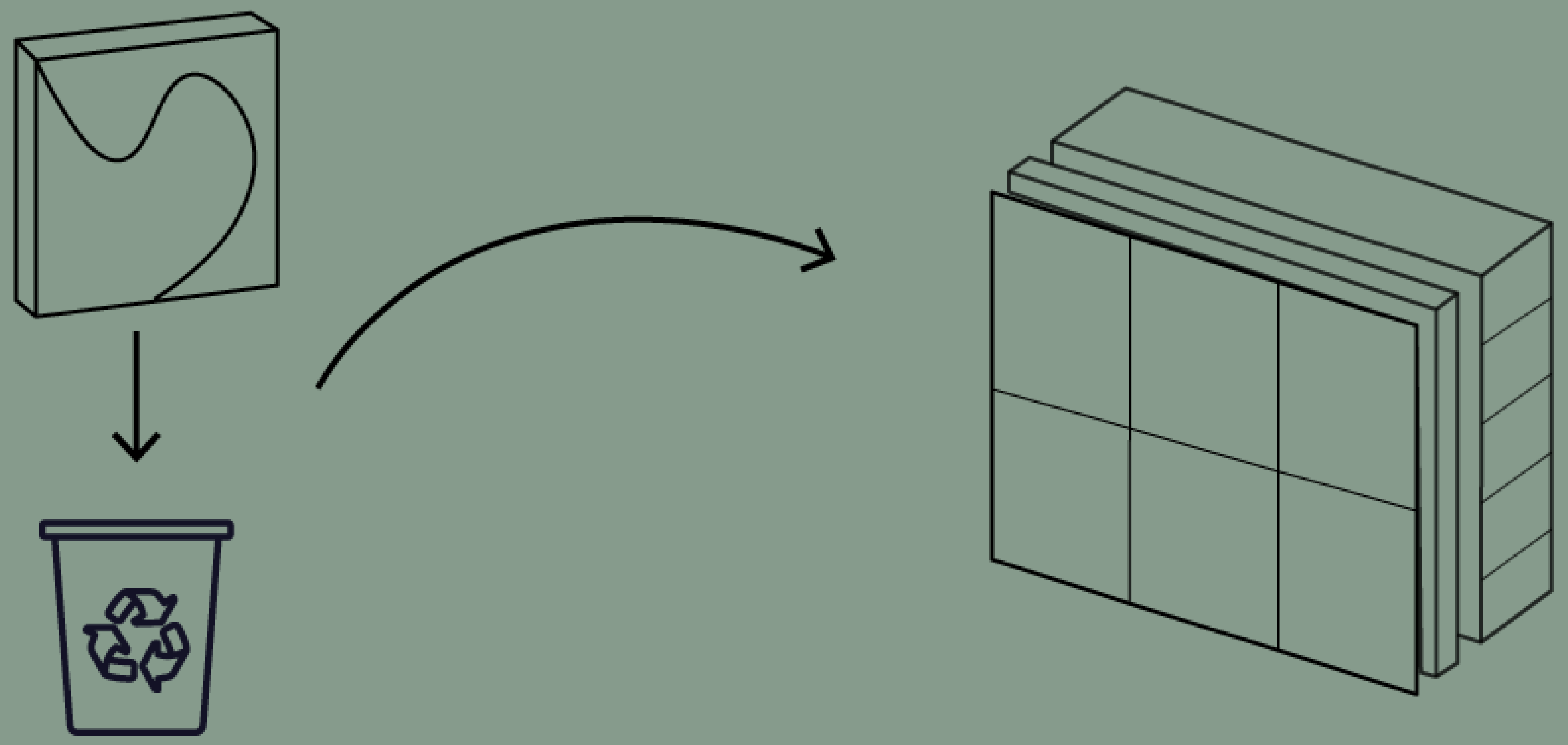
NEW

Take away for Design

- Slopes
- Ridges
- Finished surface
- Secondary facade product



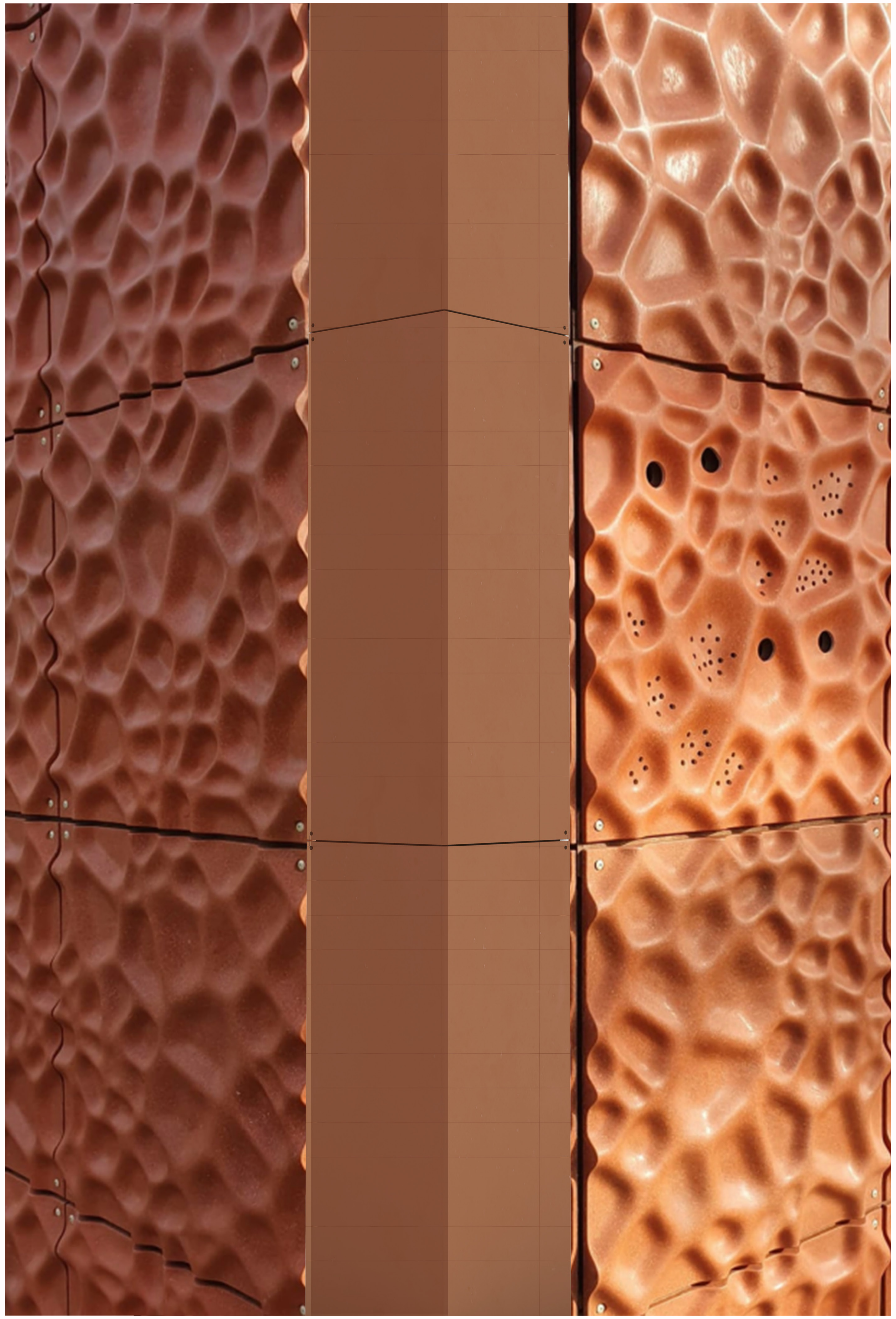
Design



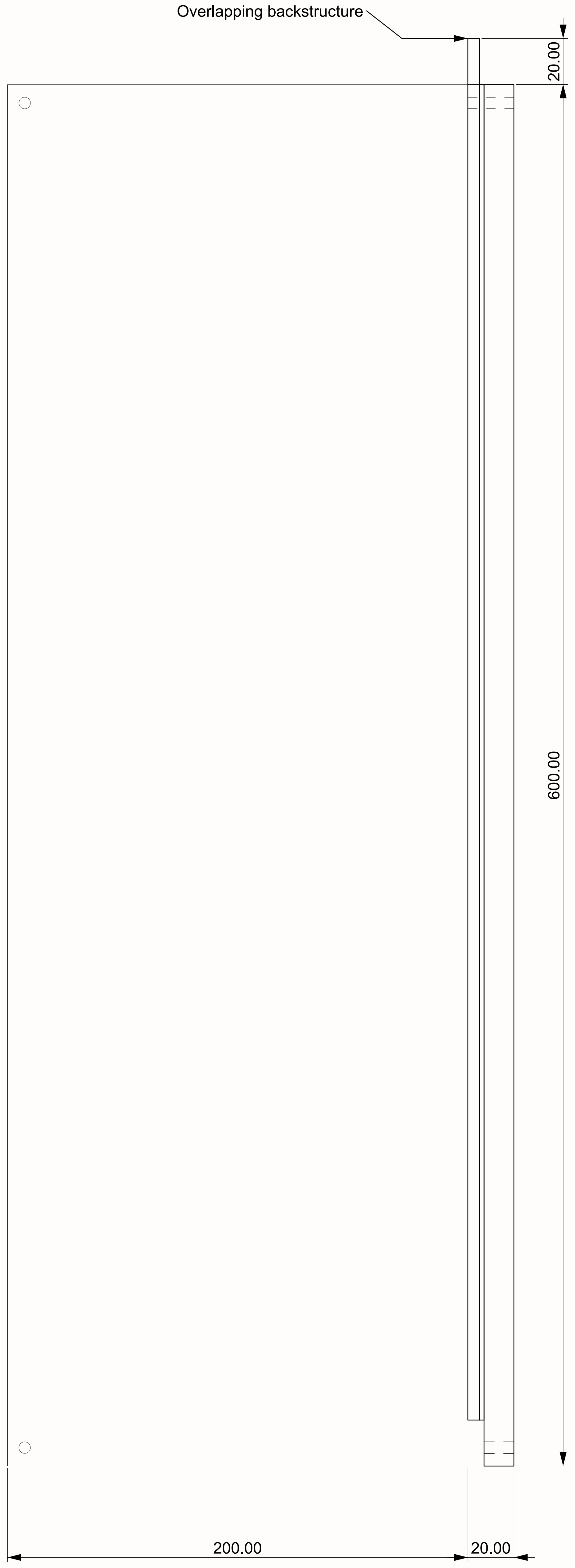
Design criteria

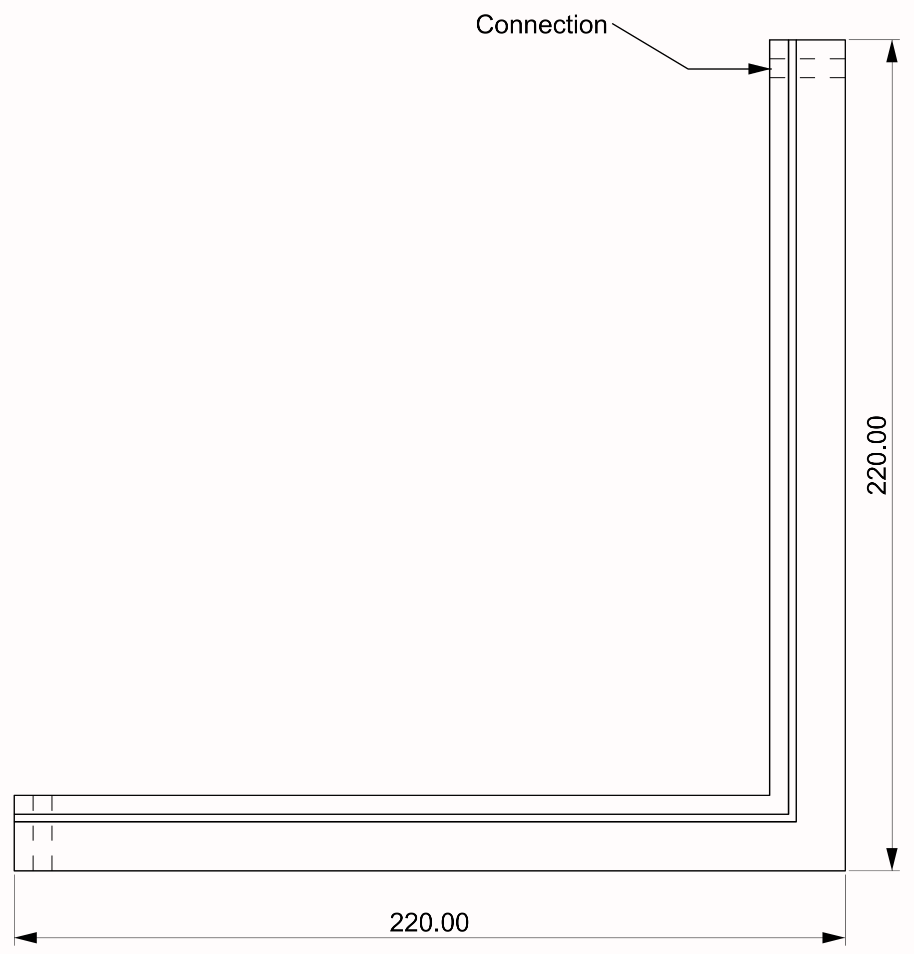
- Minimal slopes
- Avoid ridges
- Compatible
- Corner panel

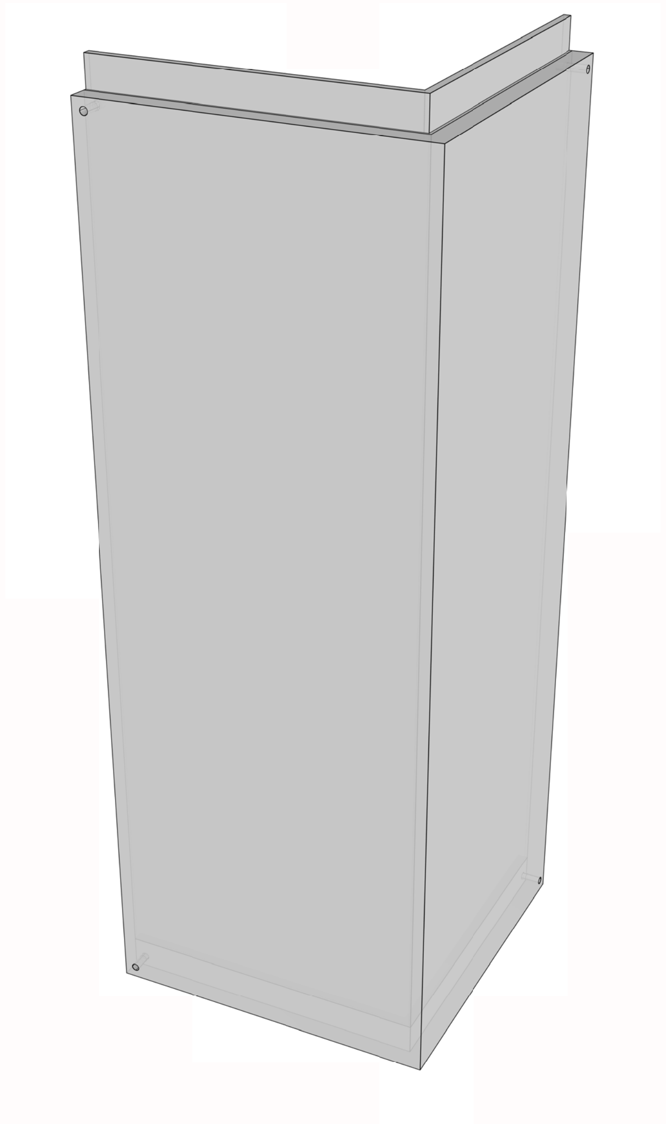
Design corner panel



Design detail

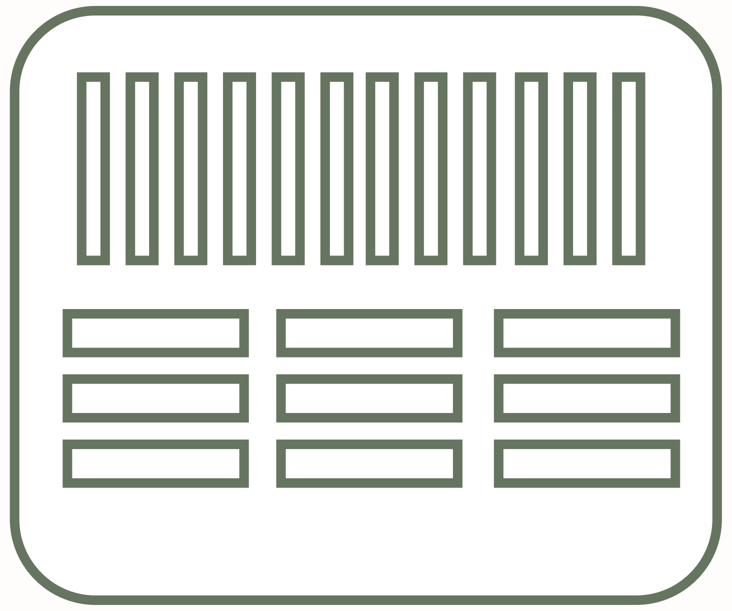




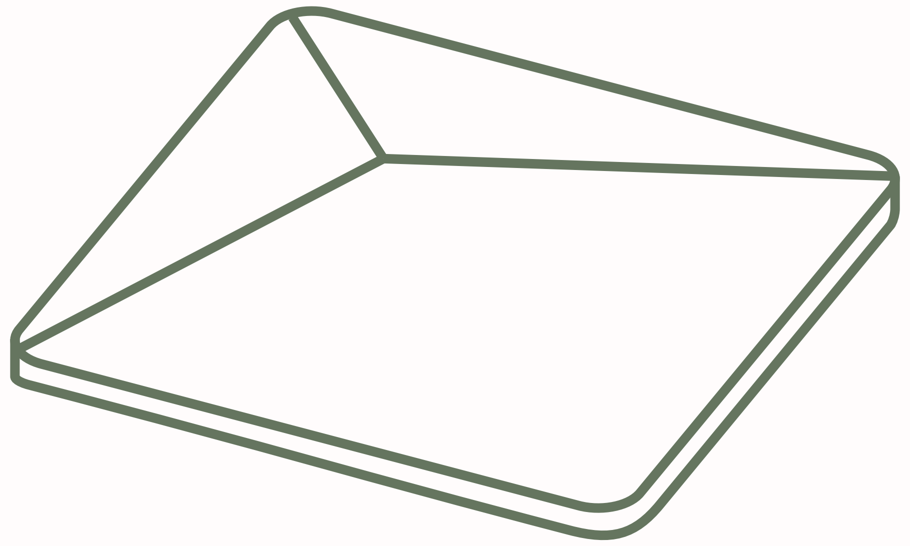


Conclusion

Recyclable



Material properies



Product

Questions?

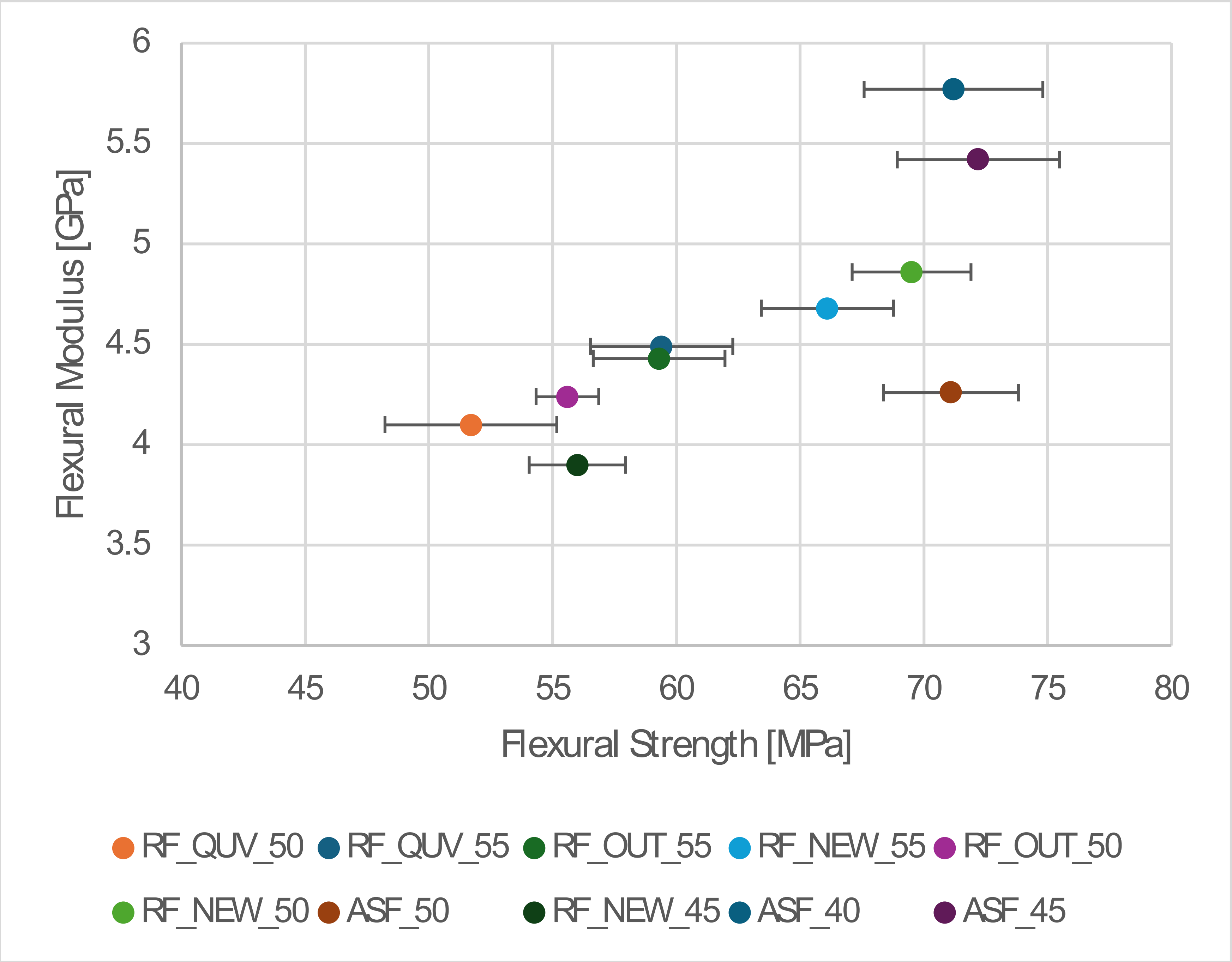
Jet Wiersma

MSc in Architecture, Urbanism and Building Science Track - Building Technology
Mentors: dr. Olga Ioannou & Prof. dr. Mauro Overend

TU Delft

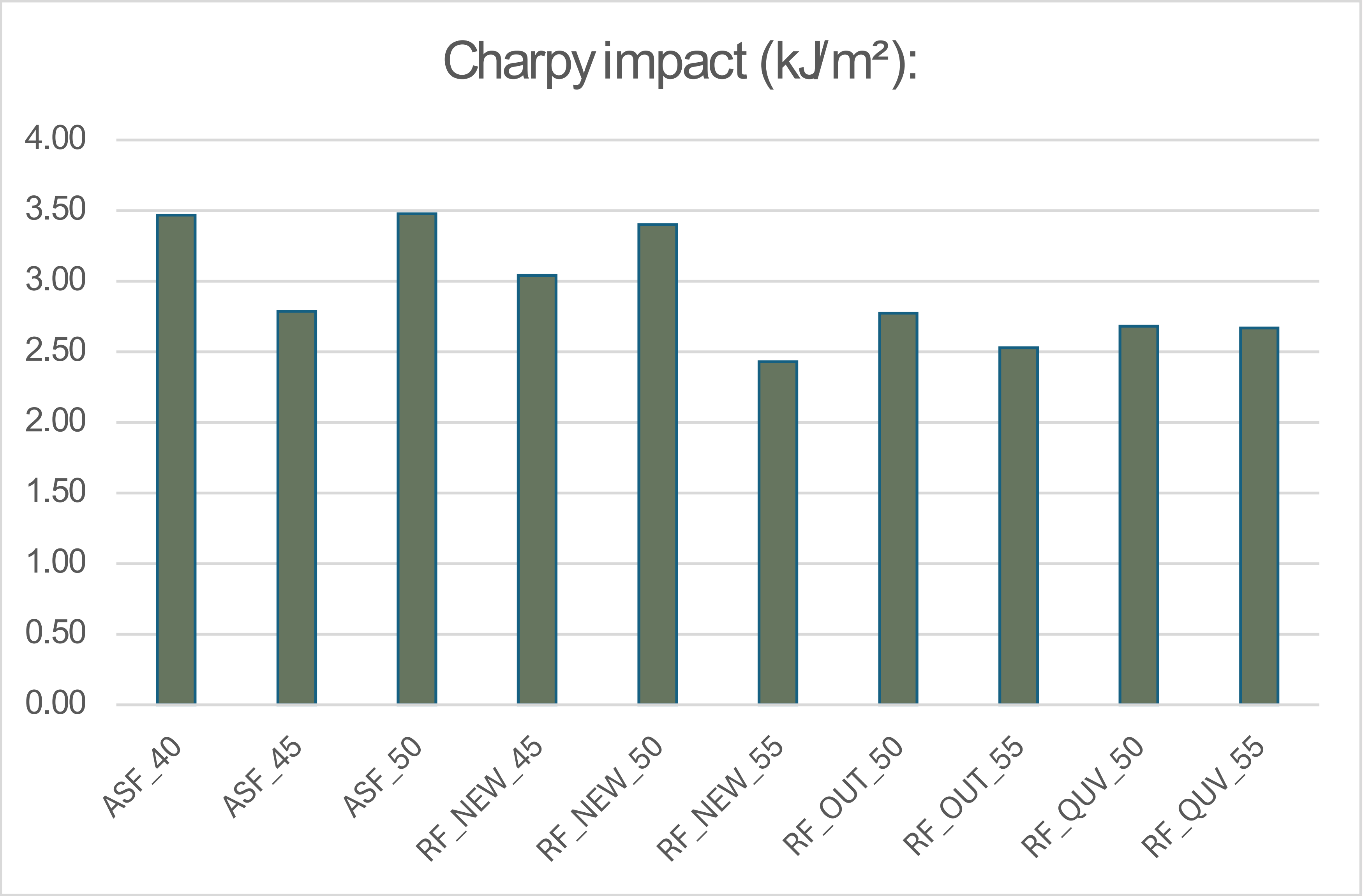
Results phase 2
Flexural strength

Name sample	Flexural strength (mean)	Flexural modulus (mean)	flexural strain	fk
ASF_40	71.2	5.77	1.3	62.46
ASF_45	72.2	5.42	1.3	60.82
ASF_50	71.1	4.26	1.2	61.70
RF_NEW_45	56	3.9	1.5	48.13
RF_NEW_50	69.5	4.86	1.5	60.74
RF_NEW_55	66.1	4.68	1.4	57.16
RF_OUT_50	55.6	4.24	1.3	44.02
RF_OUT_55	59.3	4.43	1.4	52.92
RF_QUV_50	51.7	4.1	1.4	47.96
RF_QUV_55	59.4	4.49	1.4	55.73



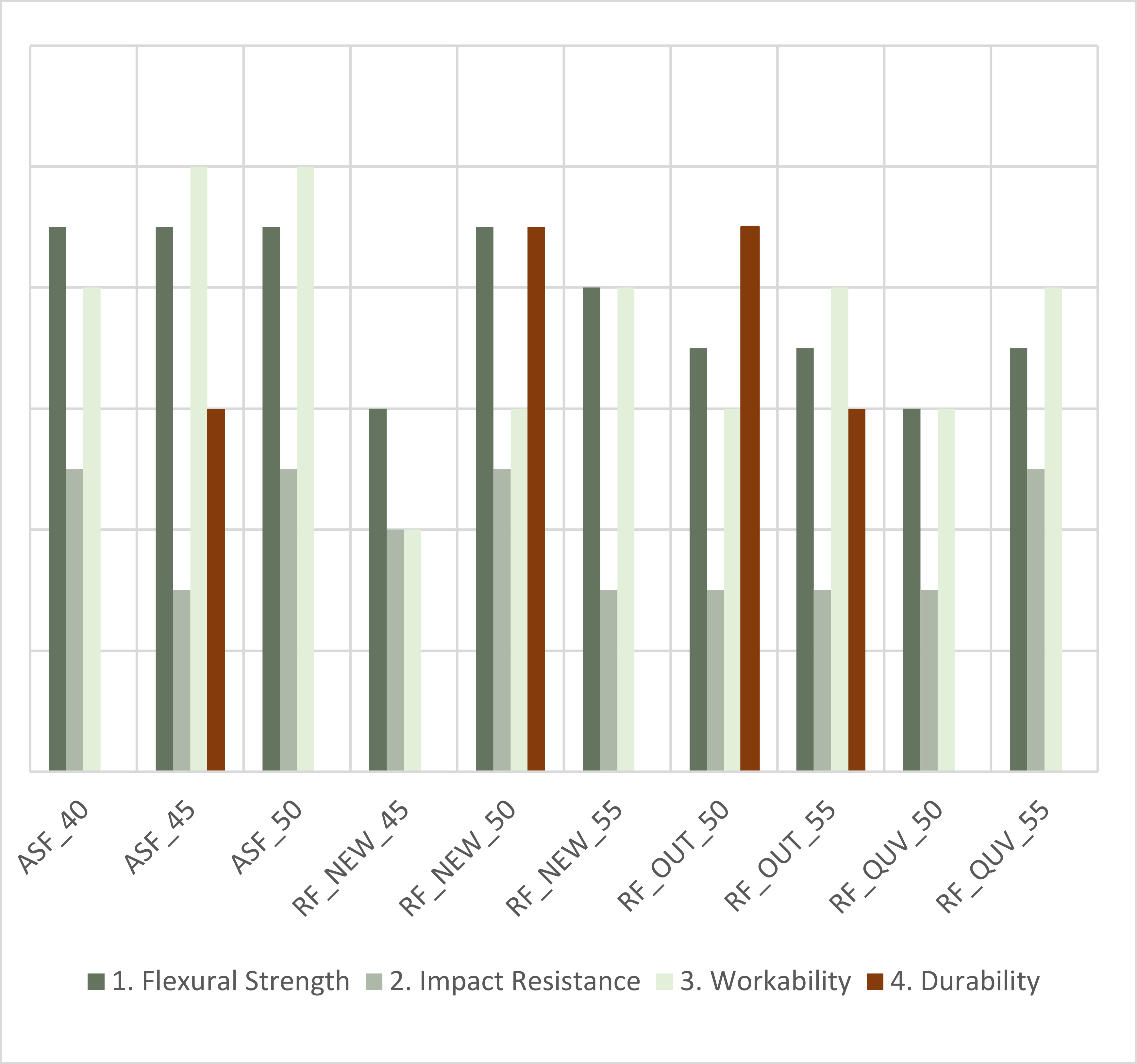
Results phase 2
Impact resistance

Name sample	Charpy impact (kJ/m^2):	Charpy impact (kJ/m^2) SD	Charpy impact (kJ/m^2) SD/2	Energy (J)
ASF_40	3.47	0.65	0.32	0.18
ASF_45	2.79	0.29	0.14	0.13
ASF_50	3.48	0.49	0.25	0.27
RF_NEW_45	3.04	0.78	0.39	0.20
RF_NEW_50	3.40	0.53	0.26	0.14
RF_NEW_55	2.43	0.21	0.10	0.23
RF_OUT_50	2.77	0.67	0.34	0.15
RF_OUT_55	2.53	0.48	0.24	0.15
RF_QUV_50	2.68	0.27	0.14	0.13
RF_QUV_55	2.67	0.44	0.22	0.13



Results phase 2
Comparison

Samples	1. Flexural Strength	2. Impact Resistance	3. Workability	4. Durability	Average	.	4.1 Frost	4.2 Water absorption	4.3 QUV Results
ASF_40	4.5	2.5	4	x	**3.7**		x	x	x
ASF_45	4.5	1.5	5	3.3	**3.6**		3	4	3
ASF_50	4.5	2.5	5	x	**4.0**		x	x	x
RF_NEW_45	3	2.0	2	x	**2.3**		x	x	x
RF_NEW_50	4.5	2.5	3	4.3	**3.6**		5	4	4
RF_NEW_55	4	1.5	4	x	**3.2**		x	x	x
RF_OUT_50	3.5	1.5	3	4.3	**3.1**		5	4	4
RF_OUT_55	3.5	1.5	4	3	**3.0**		3	3	3
RF_QUV_50	3	1.5	3	x	**2.5**		x	x	x
RF_QUV_55	3.5	2.5	4	x	**3.3**		x	x	x
Average	**3.85**	**2.0**	**3.7**		**3.225**		**4**	**3.75**	**3.5**



Evaluation scale	Strength (MPa)	2. Impact Resistance (kJ/m^2)	3. Workability	4. Durability
	Scale 0-80	**Scale 1-6**	**Scale 0-5**	**Scale 0-5**
	0 = 0-16	0 = 1-2	0 = liquid not workable	0 = total destruction
	1 = 17-32	1 = 2-3	1 = thick liquid	1= cracks and all of above
	2 = 33-48	2 = 3-4	2 = super sticky	2= deformation
	3 = 49-64	3 = 4-5	3 = sticky	3= visual change (coloration)
	4 = 65-80	4 = 5-6	4 = thick crumble (a bit sticky)	4= minimal visual change
	5= 80	5= 6	5 = crumble	5= no visual change

QUV calculations

Light hours = 504 hours

a (solar radiation) = 1615 kJ/m2

a_r (solar radiation real) = 55,5 kJ/m2

period outside = 609 days (1 year and 8 months)

$$x \; light \; hours = \frac{1}{3,6} * \frac{a * \frac{kJ}{m^2}}{0,89 \frac{W}{m^2}} \; at \; 340nm$$

LCA

A1-3

Composite ASF: 2.30 + 0.973 kg =
3.273 kg CO_2-eq/kg composite

Composite RF_NEW: 2.7075 + 0.973 kg =
3.6805 kg CO_2-eq/kg composite