SEPT 22

Le Recyclage du verre

Atelier USTV

Nancy

UNION POUR LA SCIENCE ET LA TECHNOLOGIE VERRIÈRES

FunGlass

Centre for Functional and Surface Functionalized Glass

European Commission | Horizon 2020 European Union funding for Research & Innovation

September 22nd, 2021

Advanced Glass Up-Cycling by Alkali Activation

1222·2022 800 ANNI

UNIVERSITÀ DEGLI STUDI DI PADOVA

DIPARTIMENTO DI INGEGNERIA INDUSTRIALE

FunGlass

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[2]Advanced Ceramics and Glasses group, Department of Industrial Engineering, University of Padova, Italy

Introduction

Main goal: exploration of glass for IPs
New generation of binders, alternative to conventional cements

- Binders for the building industry (e.g. Portland cement) generally having a significant environmental impact

Gelation feasible at room temperature, but high temperature processing needed for the synthesis

- Interesting replacement offered by inorganic polymers, i.e. gels typically achieved by low temperature dissolution of alumino-silicate raw materials, in alkaline environment, followed by condensation reactions

Demanding synthesis step still applied, for raw material preparation and/or definition of activating solution (e.g. alkali silicates)

This paper aims at:

- Confirming the potential of 'waste glass' as 'active' component of mixtures yielding IPs
- Defining products with different functionalities

Unrecyclable glasses: a key example

Some glasses cannot be conveniently recycled
Strict requirements on chemical purity impose always ‘virgin’ raw materials

Data in wt%

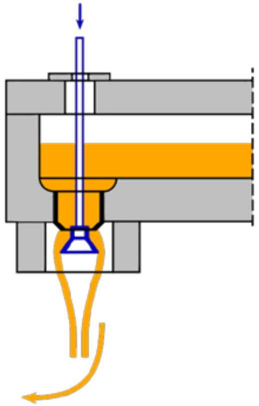
Oxides	SL glass	BS glass
SiO_2	71.6	72
Al_2O_3	1.0	7
Na_2O	13.5	6
K_2O	0.4	2
MgO	3.9	
CaO	9.0	1
B_2O_3		12
Fe_2O_3	0.1	
TiO_2		
SrO		
others	0.5	
L.O.I.		

SL: Partially unrecyclable (highly contaminated fractions)

BS: Fully Unrecyclable

Images and glass cullet courtesy of Stevanato Group (Padova, Italy)

[https://www.stevanatogroup.com/]



True recycling unfeasible according to:

- **Strict control of chemical composition and quality**
- **Industrial approach: glass pre-formed in form of tubes in one plant [Danner process] later transformed in another plant → cullet hardly transported to primary manufacturer**

Our approach

Valorization of discarded glass of any type
Attention to technologies not conditioned by the purity

Down-cycling
Savings from glass as alternative raw material (replacing minerals)

Traditional ceramics (bricks, stoneware tiles) may include glass in the formulation

Up-cycling
Savings from glass as alternative raw material (replacing minerals)

+ Added value

New glass-based engineering products

Key mission for the Advanced Ceramics & Glasses group, also in the framework of European Projects

GlaCERCo 2010-2014
CoACH 2014-2018
New-MINE 2016-2020
FunGLASS 2017-2024

SEVENTH FRAMEWORK PROGRAMME

HORIZON 2020
Horizon 2020 European Union Funding for Research & Innovation

MARIE CURIE ACTIONS

COACH European Training Network

FunGlass

NEW-MINE
EU TRAINING NETWORK FOR RESOURCE RECOVERY THROUGH ENHANCED LANDFILL MINING

Sustainable Up-Cycling: no-firing option

No secondary thermal process, products exploited for the replacement of energy-intensive construction materials (e.g. conventional cement)

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First attempts to 'unfired' products

Geopolymers from extensive use of glass

Collaboration with Prof. A.R. Boccaccini (University of Erlangen, Germany)

Extensive glass reuse

- **FA (coal combustion) as 'usual' SiO_2/Al_2O_3 provider**
- **(Container) soda lime glass [SLG] providing BOTH SiO_2 AND alkali [Na_2O]**
- **Activation with NaOH solution [5-8-10 M]**

Mixtures designed to lead to:

SiO_2/Al_2O_3 = 5 → FA/SLG = 76/24

SiO_2/Al_2O_3 = 6 → FA/SLG = 64/36

SiO_2/Al_2O_3 = 7 → FA/SLG = 54/46

Chemical composition of raw materials (wt%) determined by XRF.

wt%	SiO_2	Al_2O_3	Na_2O	K_2O	CaO	MgO	Fe_2O_3	TiO_2
FA	54.36	24.84	0.83	3.03	2.56	2.06	8.28	1.07
SLG	70.5	3.2	12	1	10	2.3	0.42	0.07

Construction and Building Materials 188 (2018) 1077–1084

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

ELSEVIER

Extensive reuse of soda-lime waste glass in fly ash-based geopolymers

N. Toniolo [a], A. Rincón [b], J.A. Roether [c], P. Ercole [d], E. Bernardo [b,*], A.R. Boccaccini [a,*]

[a] Institute of Biomaterials, Department of Materials Science and Engineering, University of Erlangen-Nuremberg, Cauerstraße 6, 91058 Erlangen, Germany
[b] Department of Industrial Engineering, University of Padova, Via Marzolo 9, Italy
[c] Institute of Polymer Materials, University of Erlangen-Nuremberg, Martensstrasse 7, 91058 Erlangen, Germany
[d] Sasil S.p.a, Regione Dosso, 13862 Brusnengo, BI, Italy

Research carried out in the framework of European Community's H2020 MSCA-ITN 'CoACH-ETN', g.a. #642557
http://www.coach-etn.eu/

COACH European Training Network

Idea: Avoiding alkali silicates

- **Useful in enhancing the SiO_2/Al_2O_3 ratio**
- **Expensive, since they imply a preliminary melting stage (and dissolution → 'water glass')**

First attempts to 'unfired' products

Geopolymers from extensive use of glass

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Key points of Geopolymers

- Condensation of **alumino-silicate hydrated 'oligomers'** [poly-sialates]
- Oligomers from **alkali activation of alumino-silicate compounds** [dissolution in **alkali** or **alkali-silicate aq. solutions**]
- Stable structures [e.g. resisting boiling tests] for (amorphous or semi-crystalline) **zeolite-like structures**: [SiO_4] tetraedra mixed with [AlO_4] tetrahedra
- **[AlO_4] tetrahedra stabilized by alkali ions**

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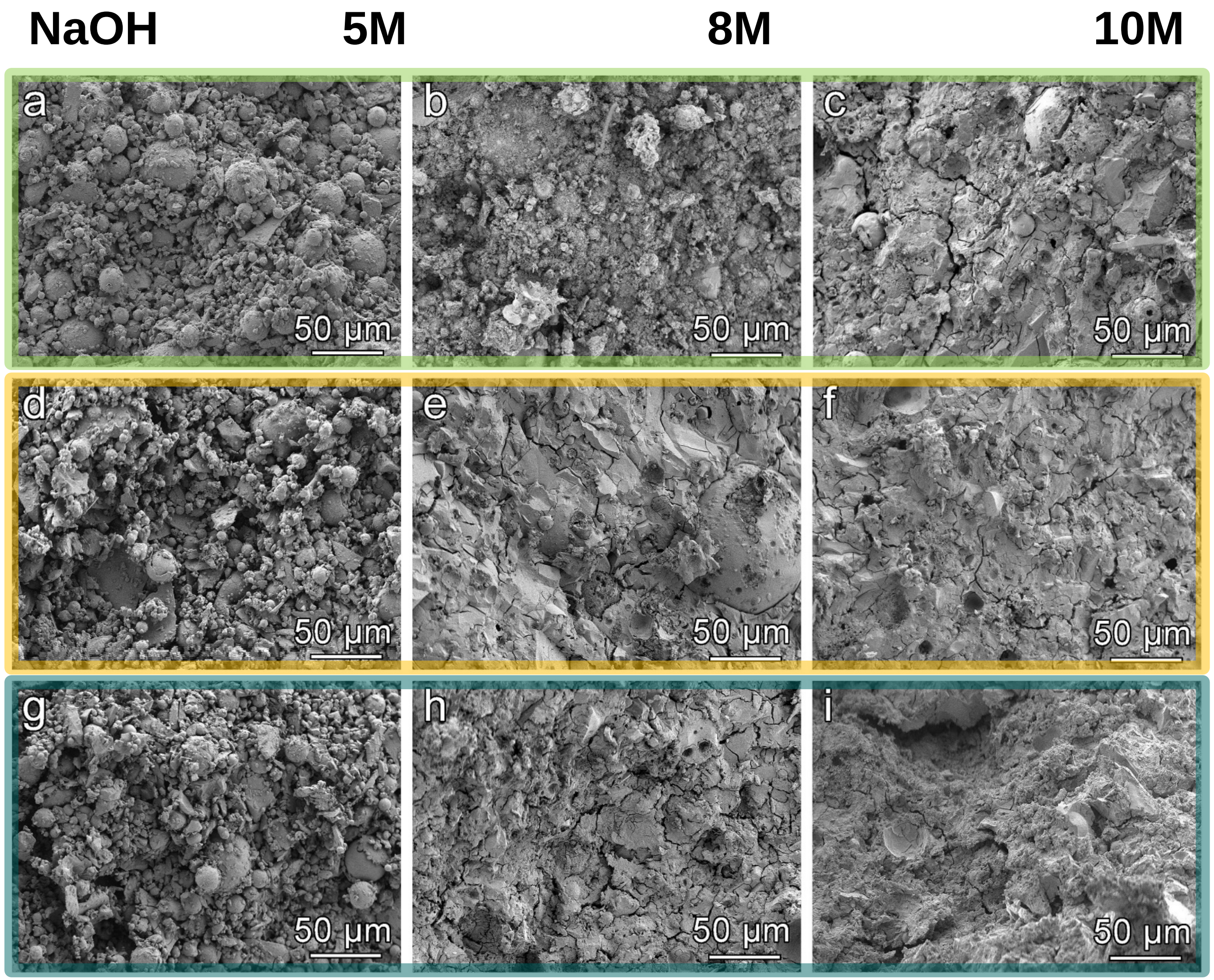
SiO_2/Al_2O_3 = 7 → FA/SLG = 54/46

- **Fine powders (FA<20 µm, SLG<30 µm)**
- **4h dissolution (solid/liquid=0.45), under mechanical stirring**
- **Curing 48 h at 60 °C**



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Stabilization of heavy metals

Element (ppm)	As	Cd	Cr	Cu	Mo	Pb	Se	Zn
6S5M	0.174	0.007	0.0251	0.11	0.363	0.1	0.038	<0.203
6S8M	0.134	0.004	0.0101	0.115	0.143	0.078	0.048	<0.203
FA	<0.049	<0.002	0.467	0.028	0.898	<0.047	0.022	<0.2
SLG	<0.049	0.001	0.043	0.036	0.007	0.018	0.018	0.088
Inert material	0.5	0.04	0.5	2	0.5	0.5	0.1	4
Non-hazardous material	2	1	10	50	10	10	0.5	50

Mixtures designed to lead to:

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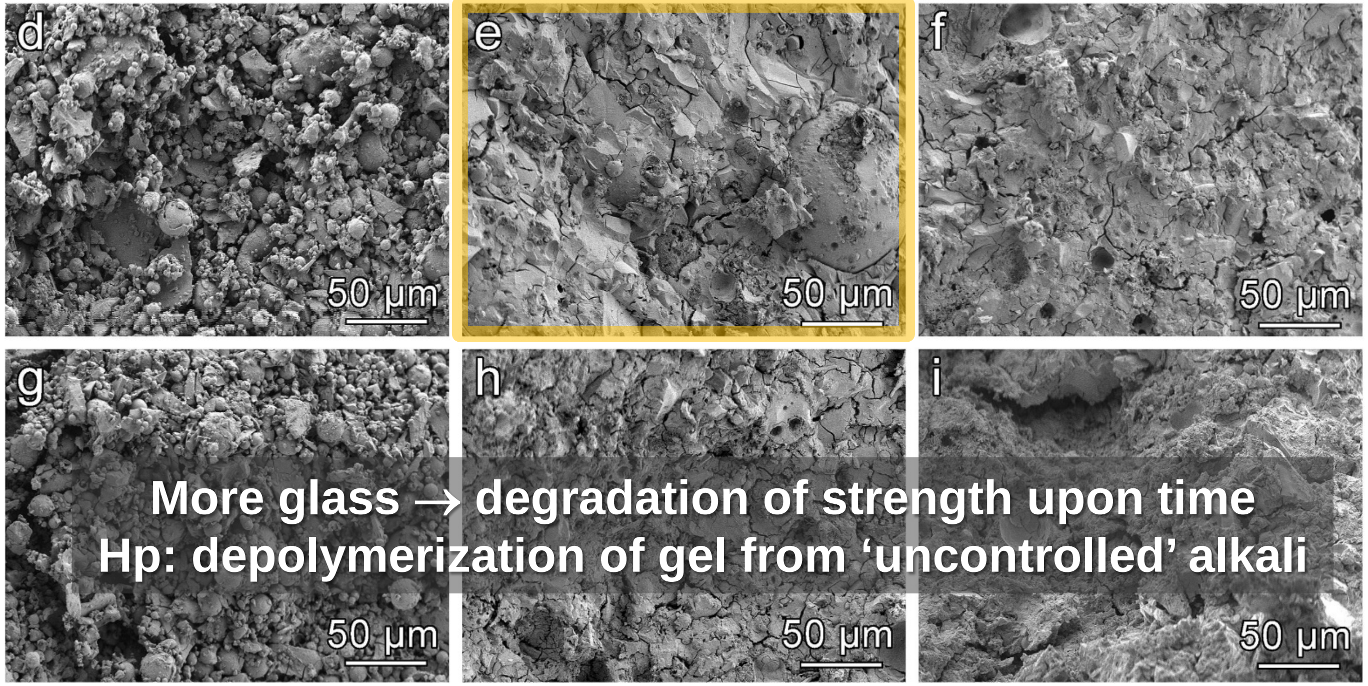
Best: evidence of reaction, higher compaction (density 1.93 ± 0.01 g/cm^3, porosity 17 vol%)

Stable compressive strength (>45 MPa, after 7 and 28 days)



More glass → degradation of strength upon time

Hp: depolymerization of gel from 'uncontrolled' alkali

FunGlass approach

Recovery of experiences on geopolymers from reactive silica
Waste glass as reactive silica, combined with Na aluminate

Instead of

Reactive SiO_2/Al_2O_3 raw material + (Na_2O or Na_2O/SiO_2) activator → GP

'Alternative approach' to geopolymers:

Reactive SiO_2 raw material + (Na_2O/Al_2O_3) activator → GP

E.g. silica fume, rice husk ash, microsilica [=agricultural or industrial waste]

Fundamental papers by *K.J. MacKenzie and collaborators [Victoria University of Wellington, NZ]*
G. Gluth & C. Jäger and collaborators [BAM, Berlin, Germany]

e.g. Brew et al., J. Mat . Sci. **42**, 3990–93 (2007)
Greiser et al., RSC Advances **8**(70), 40164-71 (2018)

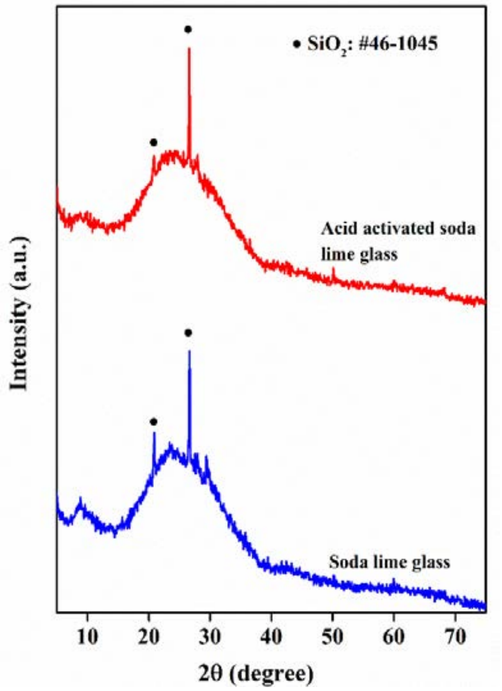
This paper:

- **Fine soda-lime glass as SiO_2 precursor** →**Attention: SLG actually providing also Na_2O!**
- **Activation by means of aquous solution of commercial $NaAlO_2$**

Starting solution: **45 wt % $NaAlO_2$ in distilled water;**
slow mixing at room temperature for 30 min

FunGlass approach

Recovery of experiences on geopolymers from reactive silica
Waste glass as reactive silica, combined with Na aluminate



Starting solution: **45 wt % $NaAlO_2$** **(Sigma Aldrich, Gillingham, UK); slow mixing at room temperature for 30 min**

Route #1

- **Fine powder of SLG (30µm in size) cast in $NaAlO_2$ solution, in a proportion 50/50 wt %**
- **Mixing for 3h, under the low speed mechanical stirring (300 rpm)**
- **Casting in PS moulds and curing at 75 °C, 7 days**

Overall $NaAlO_2$/SLG = 0.31

Route #2: preliminary acid leaching

- **Fine powder of SLG (30µm in size) cast in distilled water; pH = 5 by addition of concentrated HCl solution**
- **3h leaching (pH monitored and kept ~ 5 by periodical dropwise addition of HCl solution)**
- **Washing and centrifugation in distilled water (6 cycles) + drying at 40 ⁰C, overnight**
- **Fine powder of treated SLG cast in $NaAlO_2$ solution, in a proportion 50/50 wt %**
- **Mixing for 3h, under the low speed mechanical stirring (300 rpm)**
- **Casting in PS moulds and curing at 75 °C, 7 days**

Preliminary test: survival in boiling water [30 min; 4g in 50 cl]→No disintegration, no dissolution

FunGlass approach

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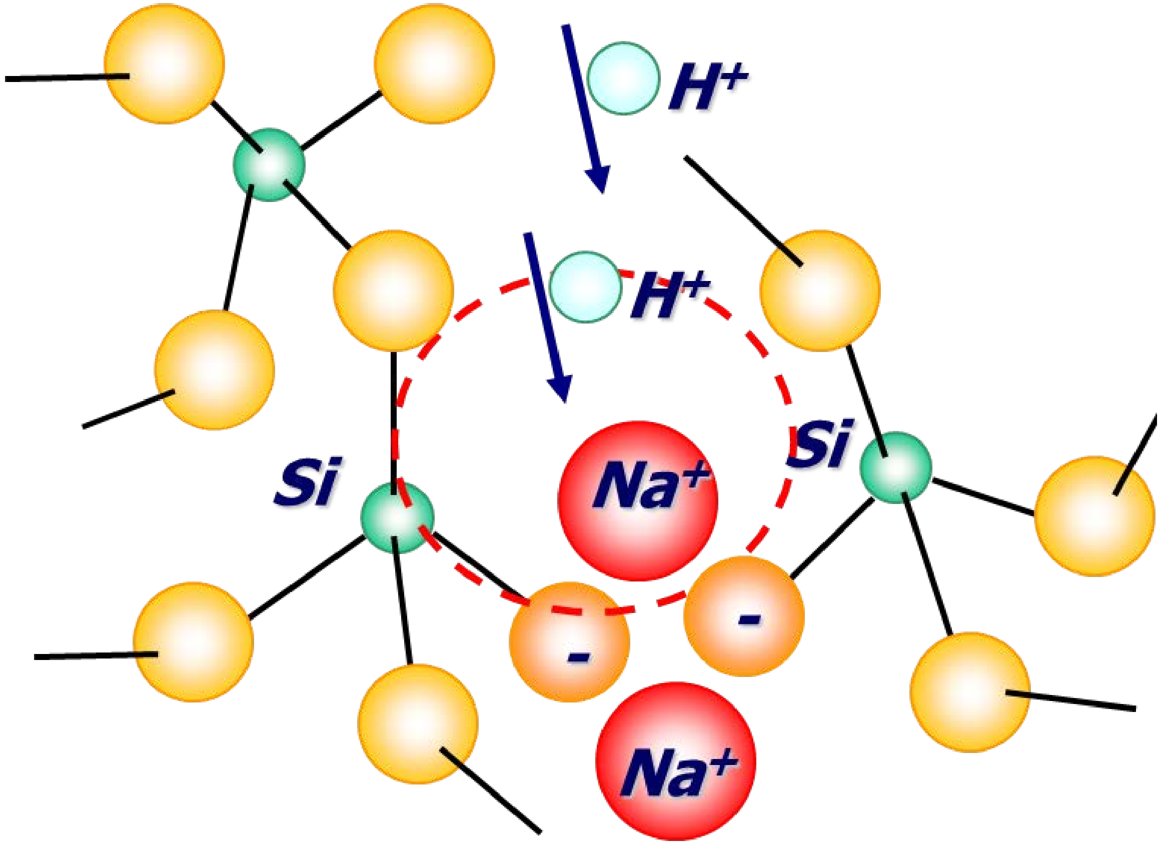
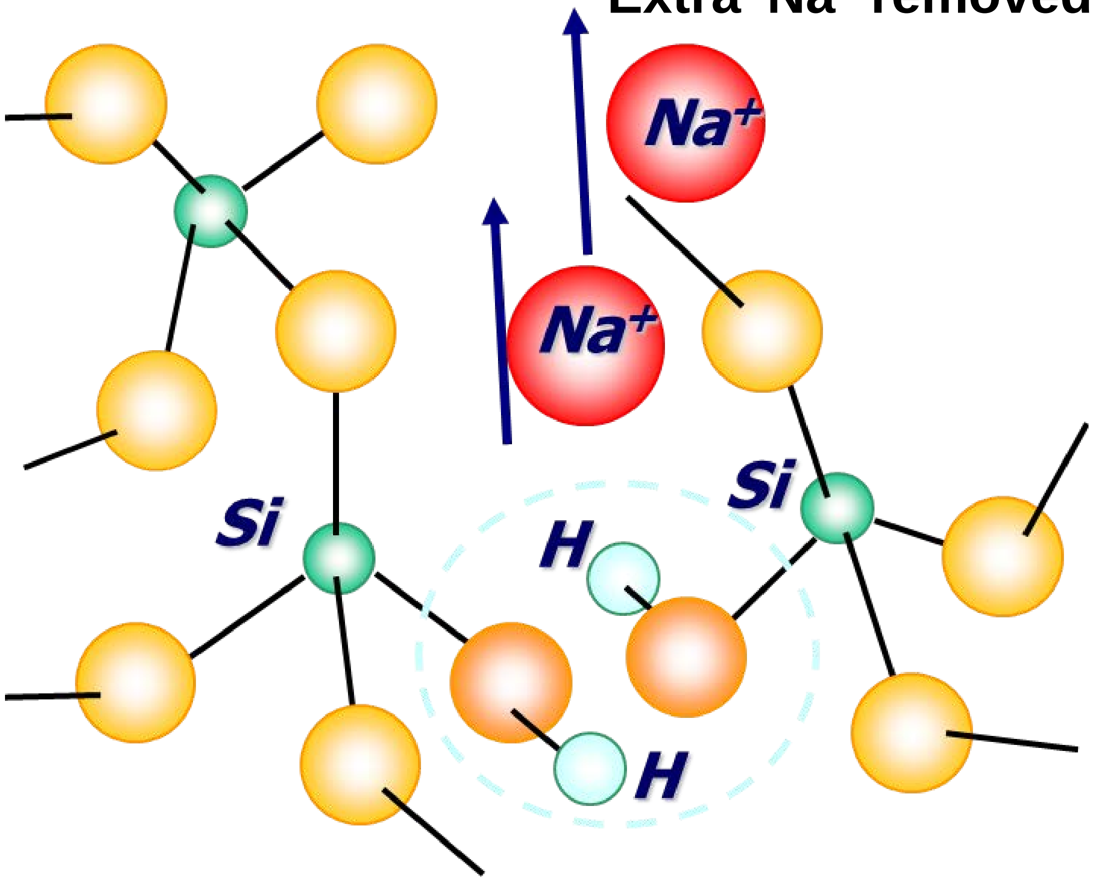
Waste glass as reactive silica, combined with Na aluminate



Acid leaching: protons replacing Na^+

Additional treatment, but it may be applied to recover metals (e.g. lamps, PV panels)

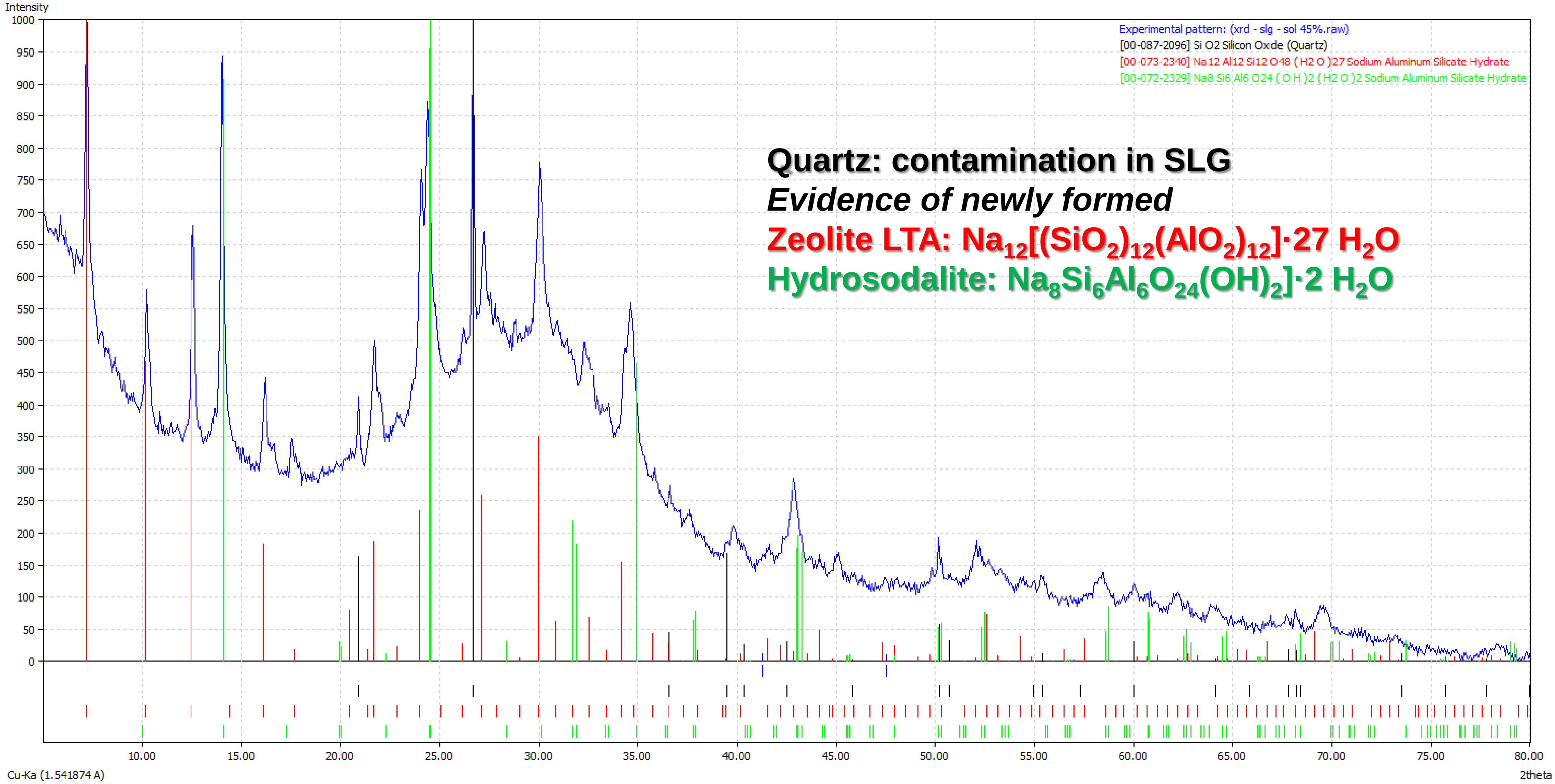
‘Extra’ Na^+ removed



Hydrated silica expected to react with the activating solution (gelation with Na^+ just from solution)

Results: mineralogy

No acid leaching: semi-crystalline material Hydrosodalite + Zeolite LTA



Quartz: contamination in SLG

Evidence of newly formed

Zeolite LTA: $Na_{12}[(SiO_2)_{12}(AlO_2)_{12}]\cdot 27\ H_2O$

Hydrosodalite: $Na_8Si_6Al_6O_{24}(OH)_2]\cdot 2\ H_2O$

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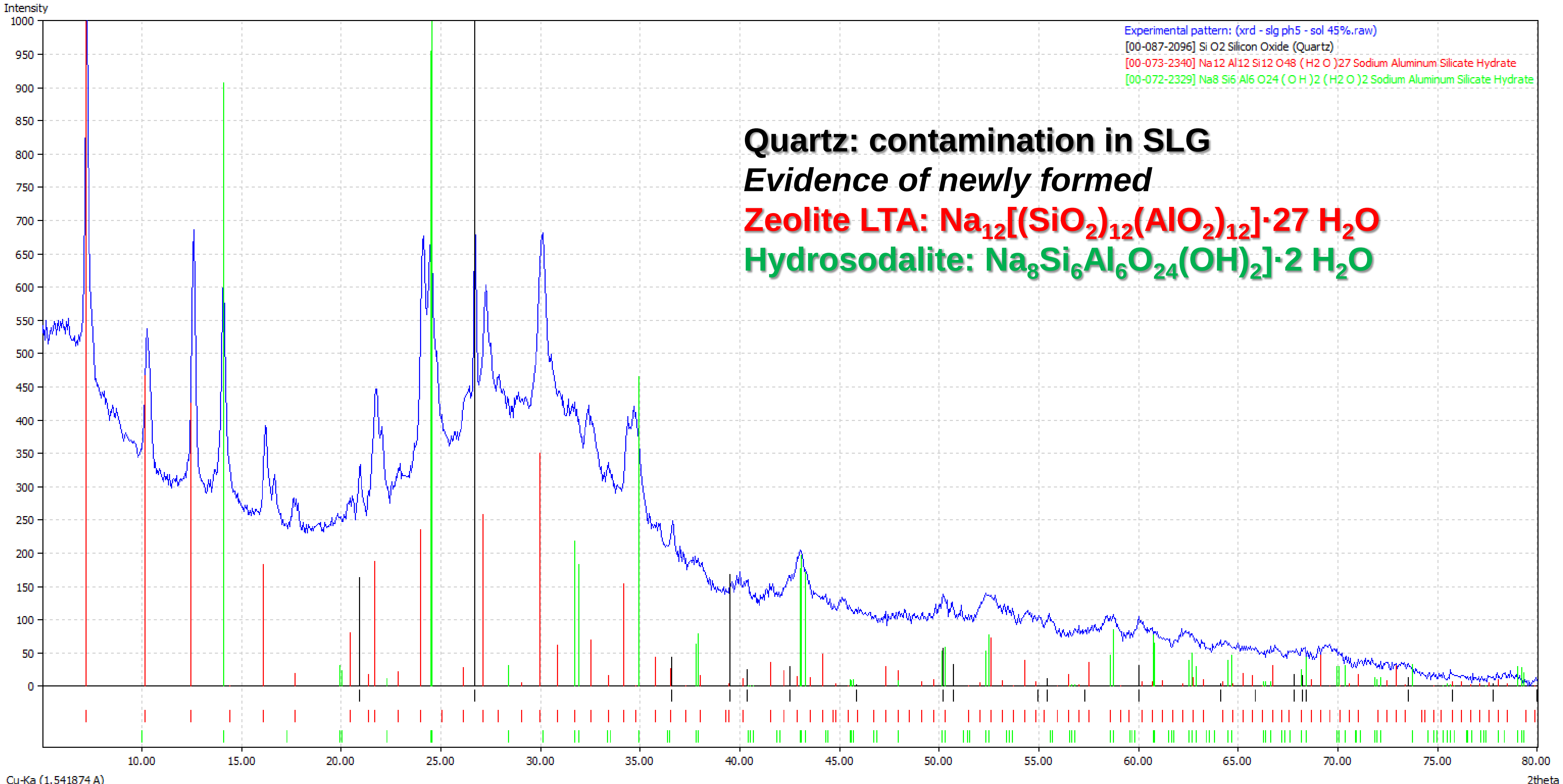
Results: mineralogy

Acid leaching: semi-crystalline material again, but different
Hydrosodalite (reduced) + Zeolite LTA (enhanced)



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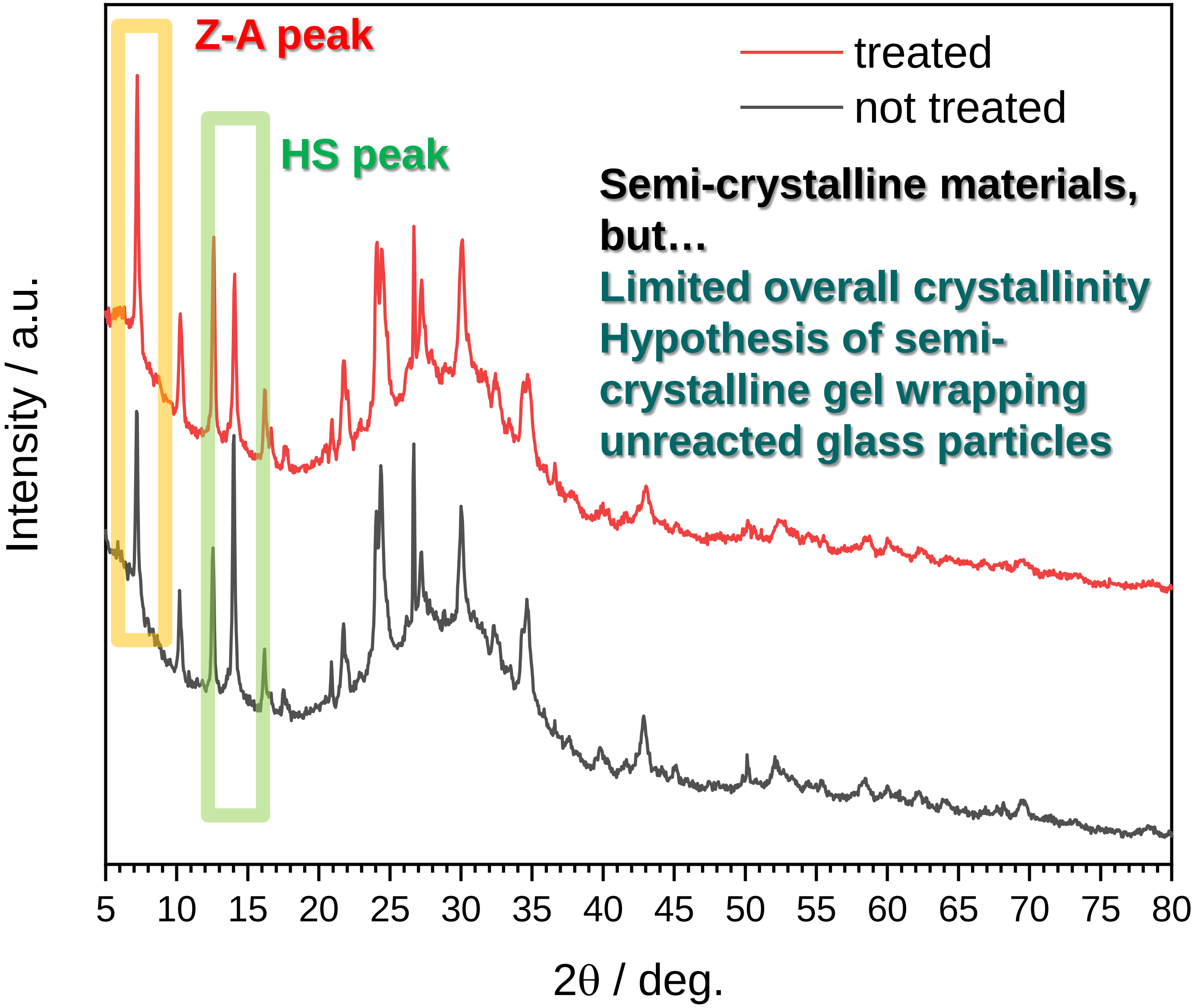
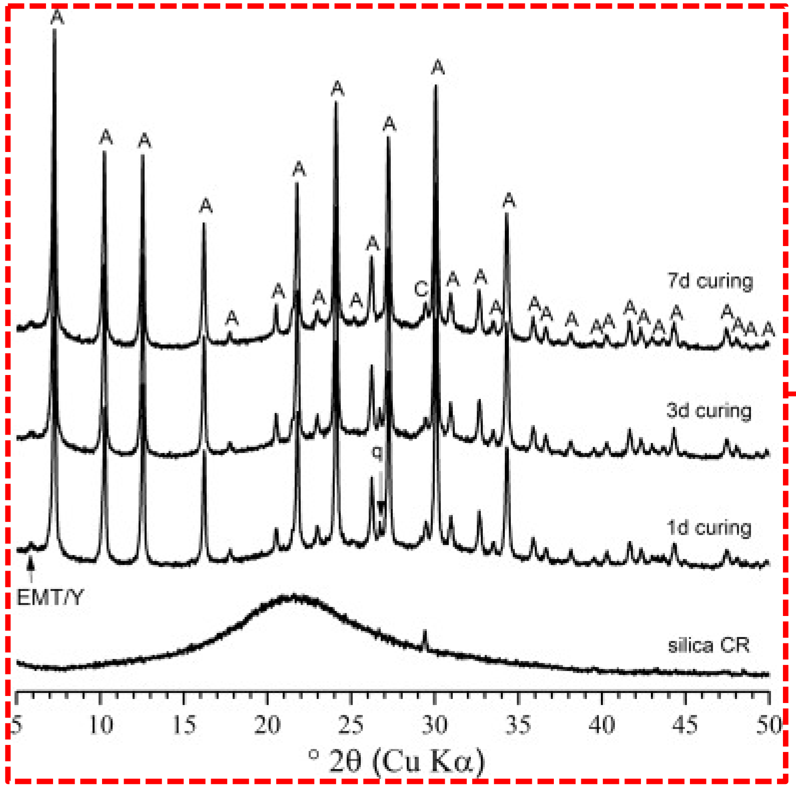
Results: mineralogy

Acid leaching: semi-crystalline material again, but different
Comparison with reference



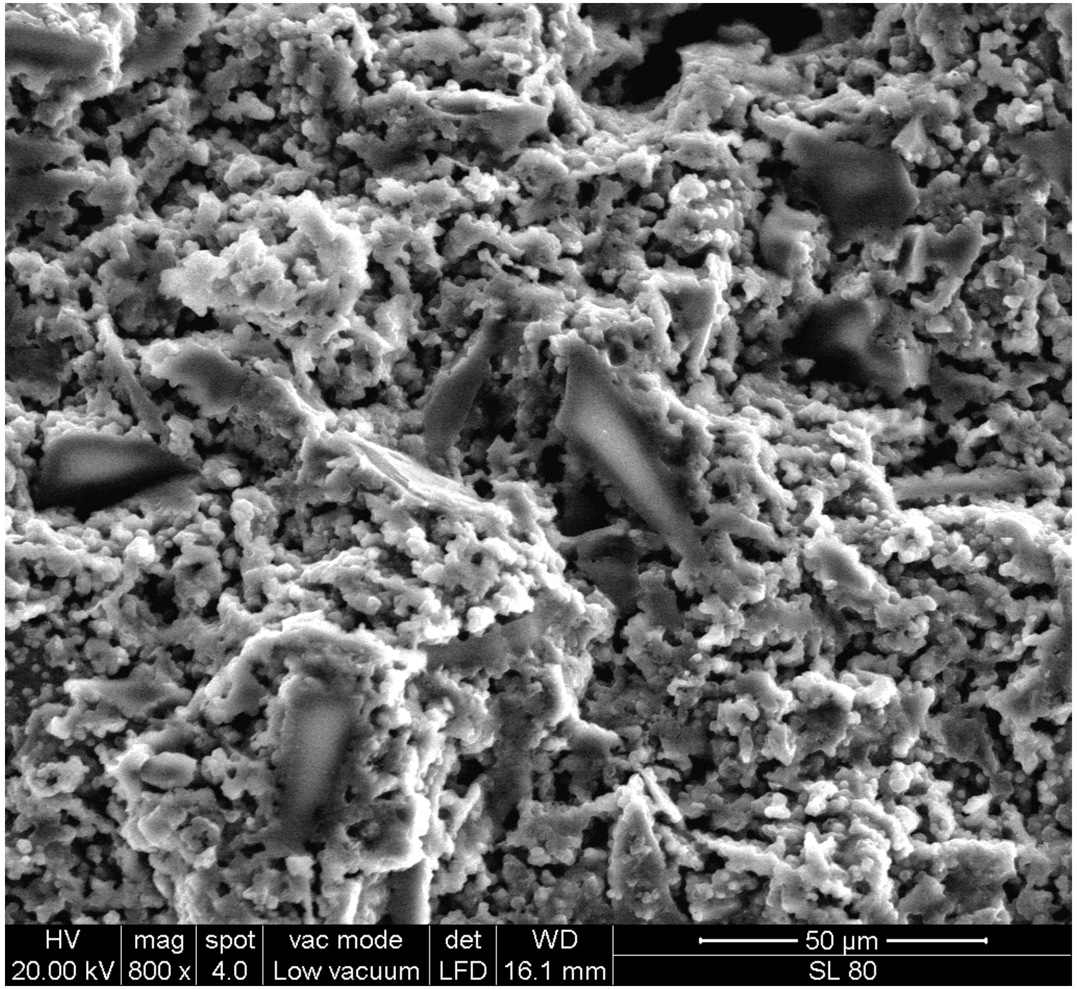


Interesting comparison with '*Geopolymer-zeolite composites*' from $NaAlO_2$ and silica waste (from chlorosilane production)
Greiser et al. Ceram. Int. 43(2), 2202-8 (2017)

Results: morphology

Evidence of abundant ‘binding phase’

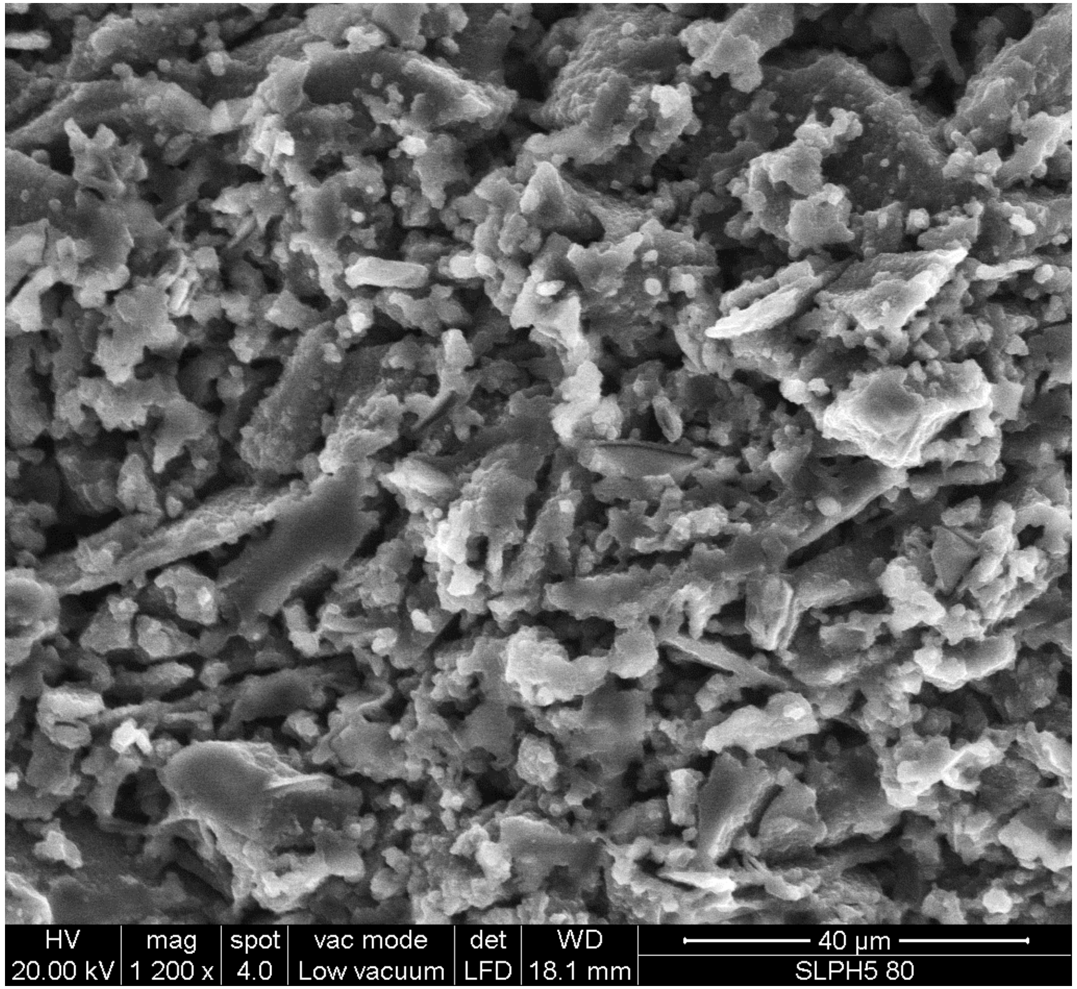
Significant dissolution of glass powders, with some differences



SLG with no treatment: well recognizable former glass granules

Binding phase ‘attached’ to glass particles

SLG after leaching: binding phase integrated at the surface



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Results: morphology

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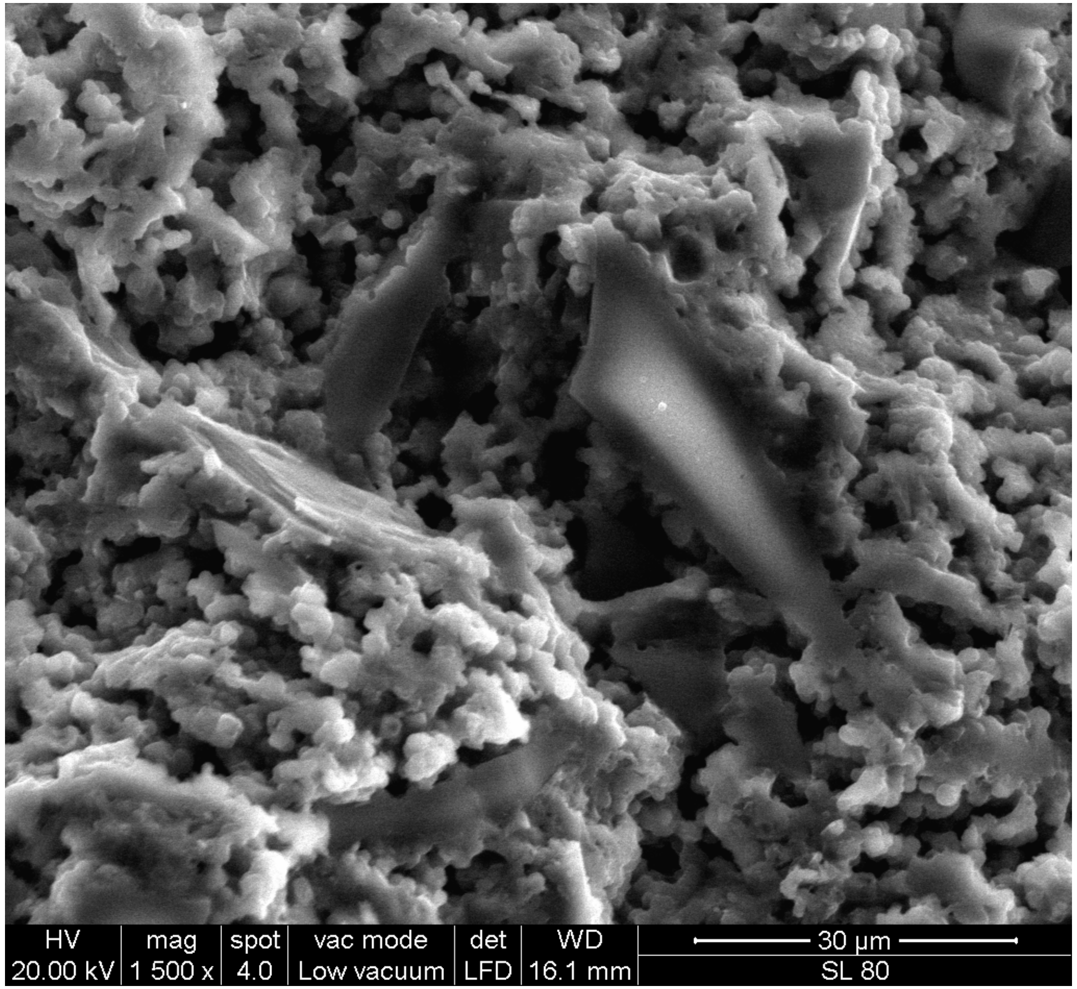
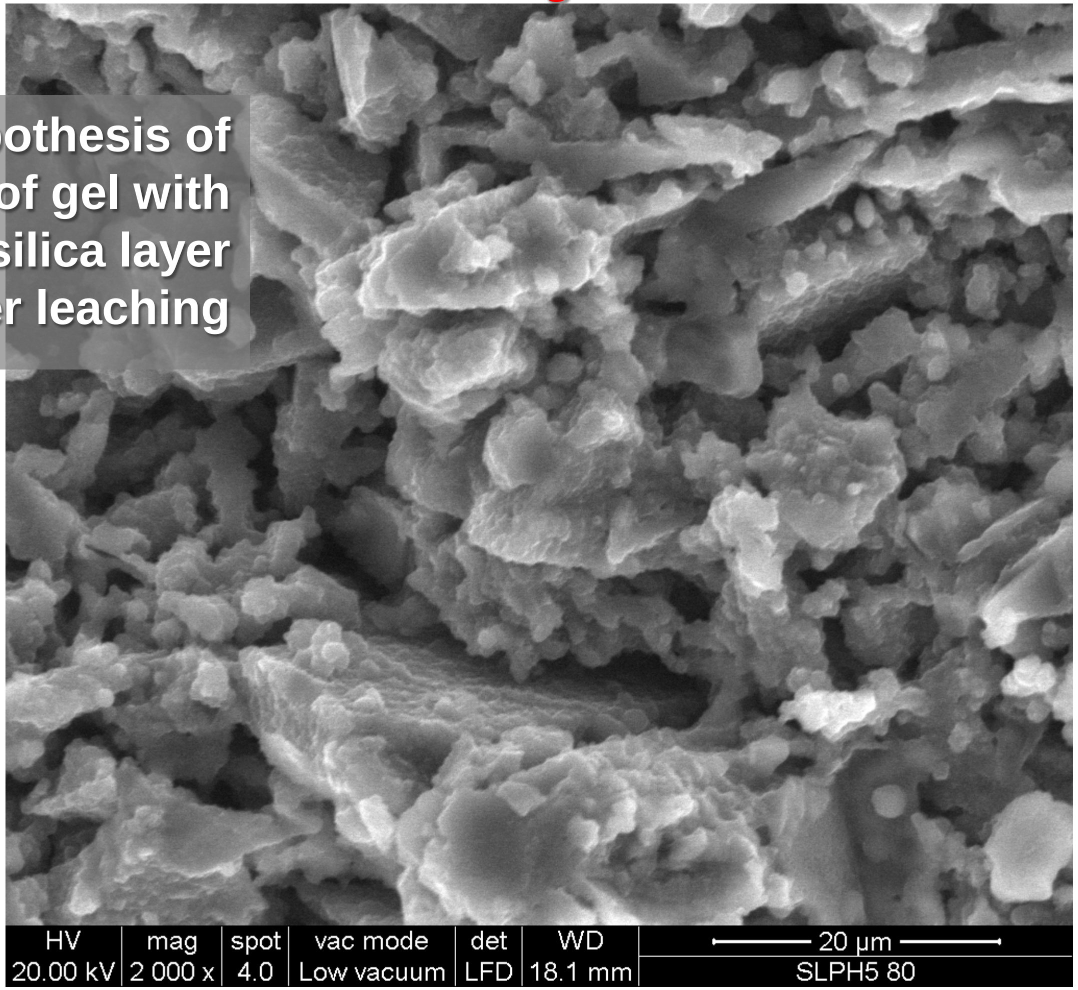


SLG with no treatment: well recognizable former glass granules

Binding phase 'attached' to glass particles

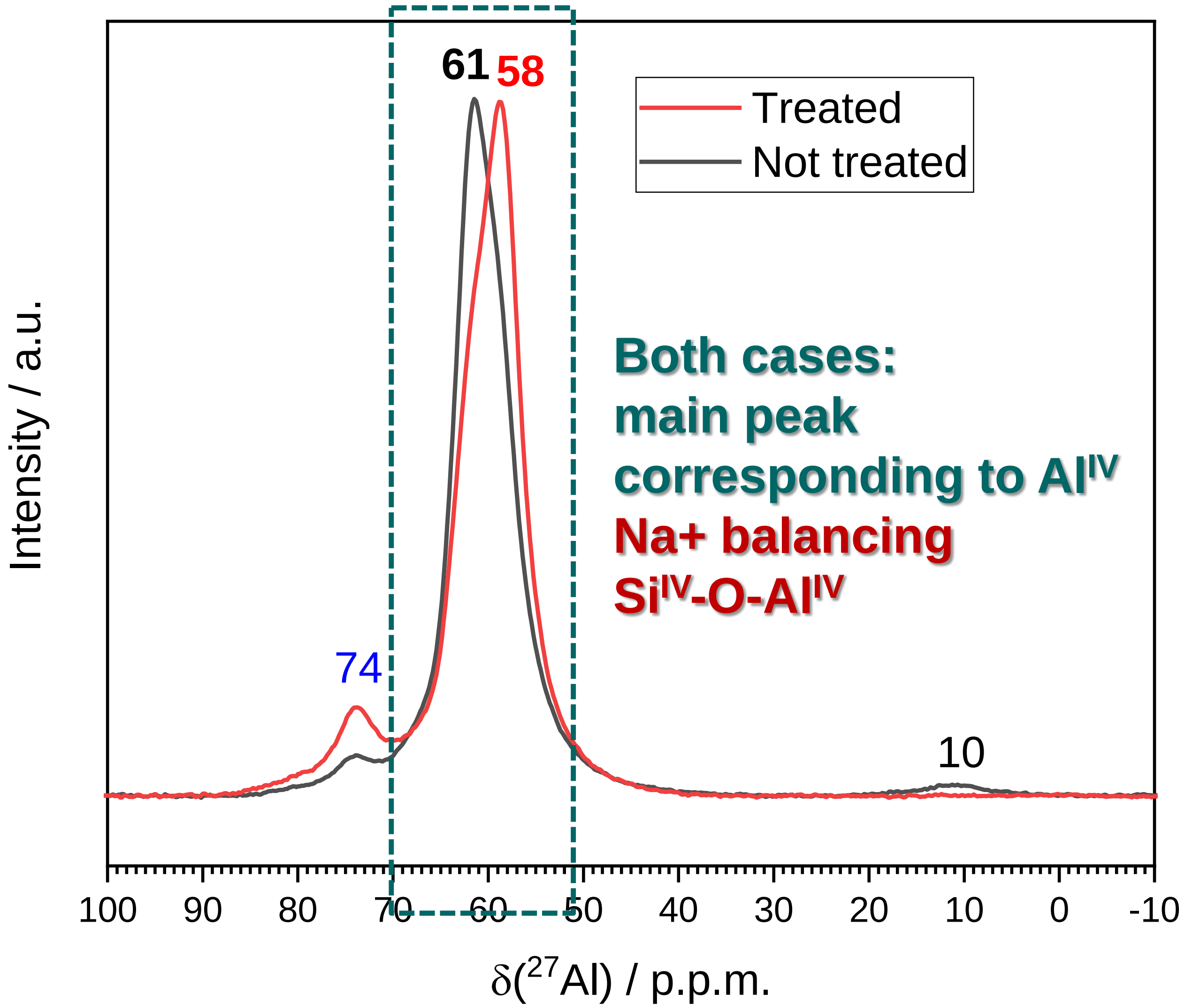
Hypothesis of integration of gel with hydrated silica layer available after leaching

SLG after leaching: binding phase integrated at the surface: texturing



Results: ^{27}Al NMR analysis

Evidence of gelation: Al ions in tetrahedral coordination
Preliminary treatment of glass powders affecting the structure of the gel



- **No signal attributable to unreacted $NaAlO_2$ (δ~80 ppm)**
- **Some signal consistent with Al^{VI} in materials from not treated SLG (AlO_6 from minor amounts of $Al(OH)_3$)**

  Brew et al., J. Mat . Sci. **42**, 3990–93 (2007)
- **Some signals consistent with Al^{V} in both materials (δ~74 ppm)**

  Walkley et al., J. Phys. Chem. C **122**, 5673–85 (2018)

More intestingly, for Al^{IV}:

Exchange of main peak and shoulder

Not treated δ~61 ppm **[shoulder at ~58]**

less ordered AlO_4 units

Walkley et al., J. Phys. Chem. C **122**, 5673–85 (2018)

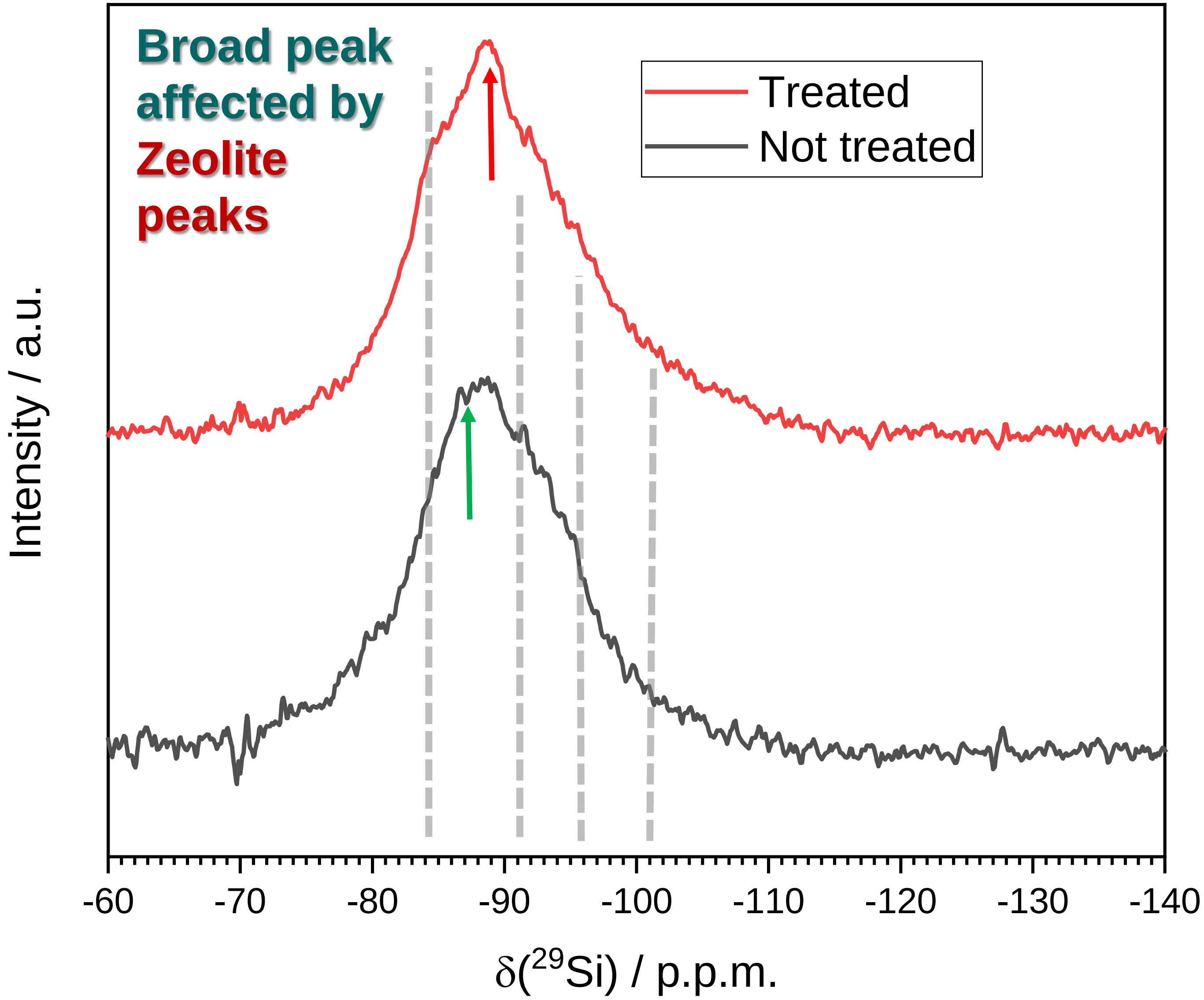
Treated δ~58 ppm **[shoulder at ~61]**

Greiser et al., RSC Advances **8**(70), 40164-71 (2018)

Results: ^{29}Si NMR analysis

Confirmation of the structural changes

Preliminary treatment of glass powders affecting the gel



Interesting match with assignements from the literature

Greiser et al., RSC Advances **8**(70), 40164-71 (2018)

δ ~ -86 ppm (not treated): hydrosodalite

δ ~ -89 ppm (treated): zeolite LTA

Signals consistent with Q^4 species in alumino-silicate gel

δ ~ -84 ppm Q^4 (4Al) [more for T]

δ ~ -91 ppm Q^4 (3Al)

δ ~ -96 ppm Q^4 (2Al) [more for NT]

δ ~ -102 ppm Q^4 (1Al)

Results: ^{29}Si NMR analysis

Confirmation of the structural changes

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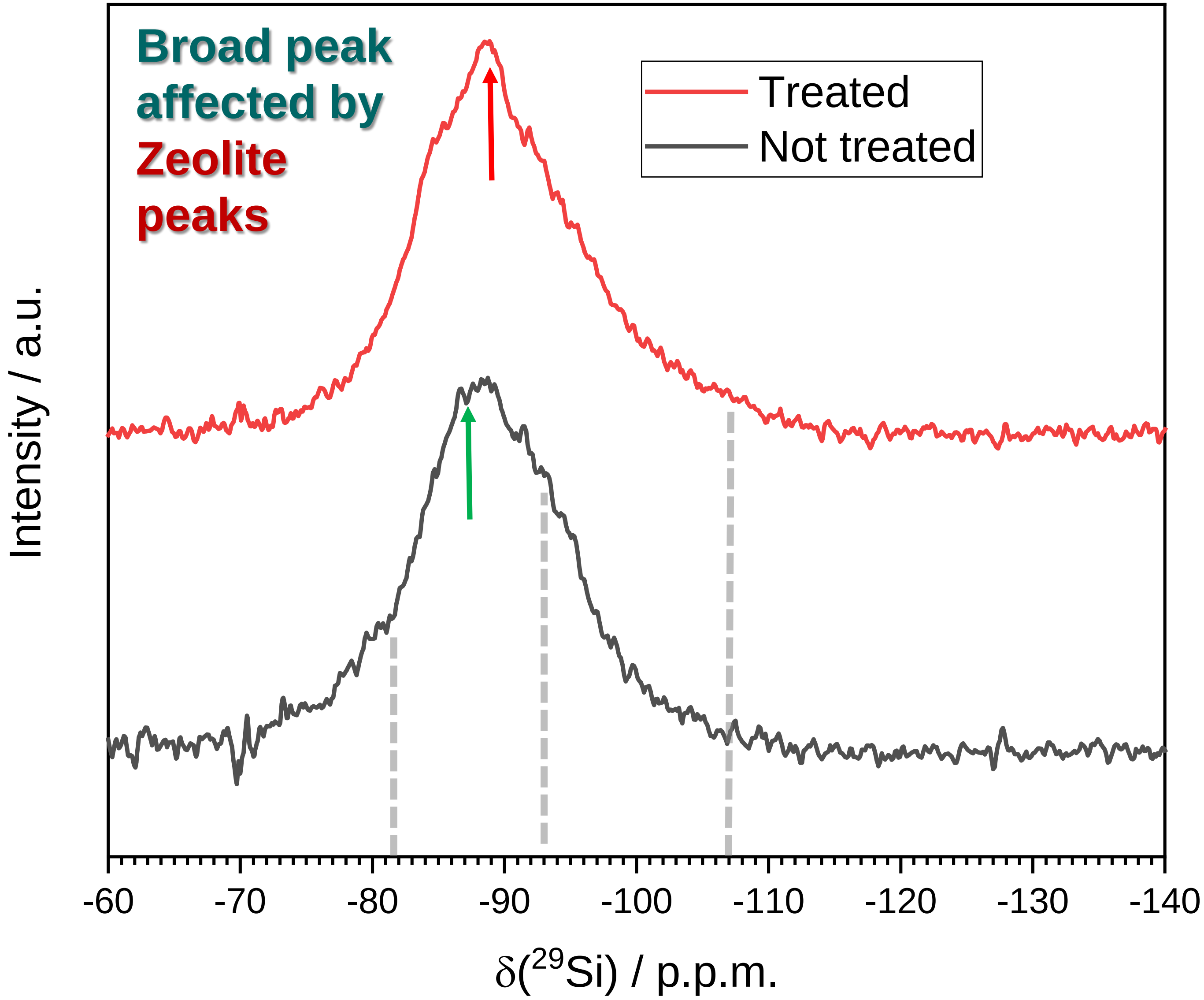


Interesting match with assignements from the literature

Signals consistent with SiO_4 species in the presence of Na^+ and Ca^{2+} ions

Jones et al., J. Non-Cryst. Sol. **293-295**, 87-92 (2001)

δ ~ -82 ppm **Q^2 [more for NT]**

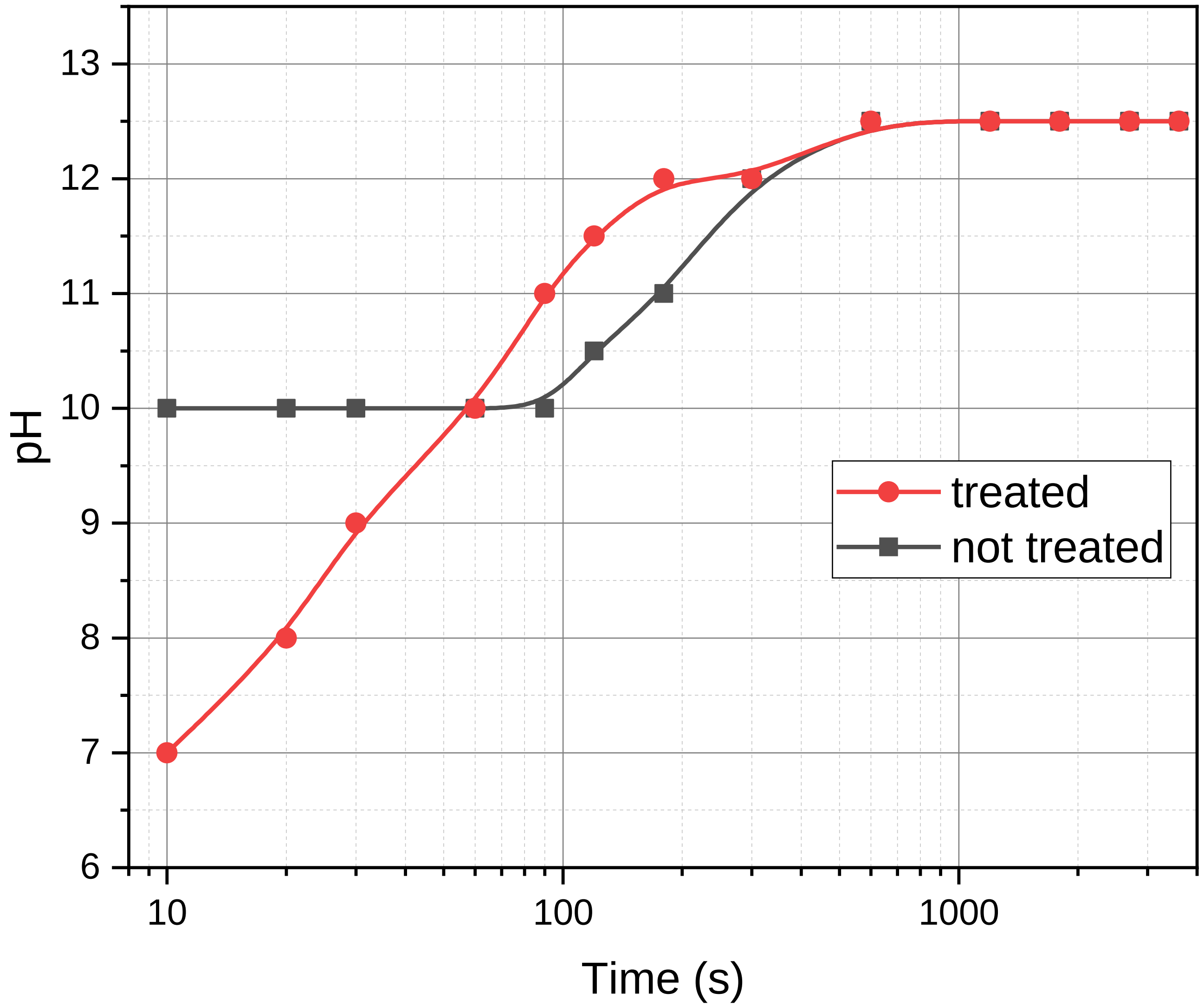
δ ~ -93 ppm **Q^3**

δ ~ -107 ppm **Q^4 [more for T]**

Hypothesis of more polymerized gel with acid pre-treatment

Alkali mobility test

Crushed gels left in distilled water
Sudden alkalinization with not treated glass



Gels crushed <2 mm

Cast in distilled water (35% solid loading)

Room temperature

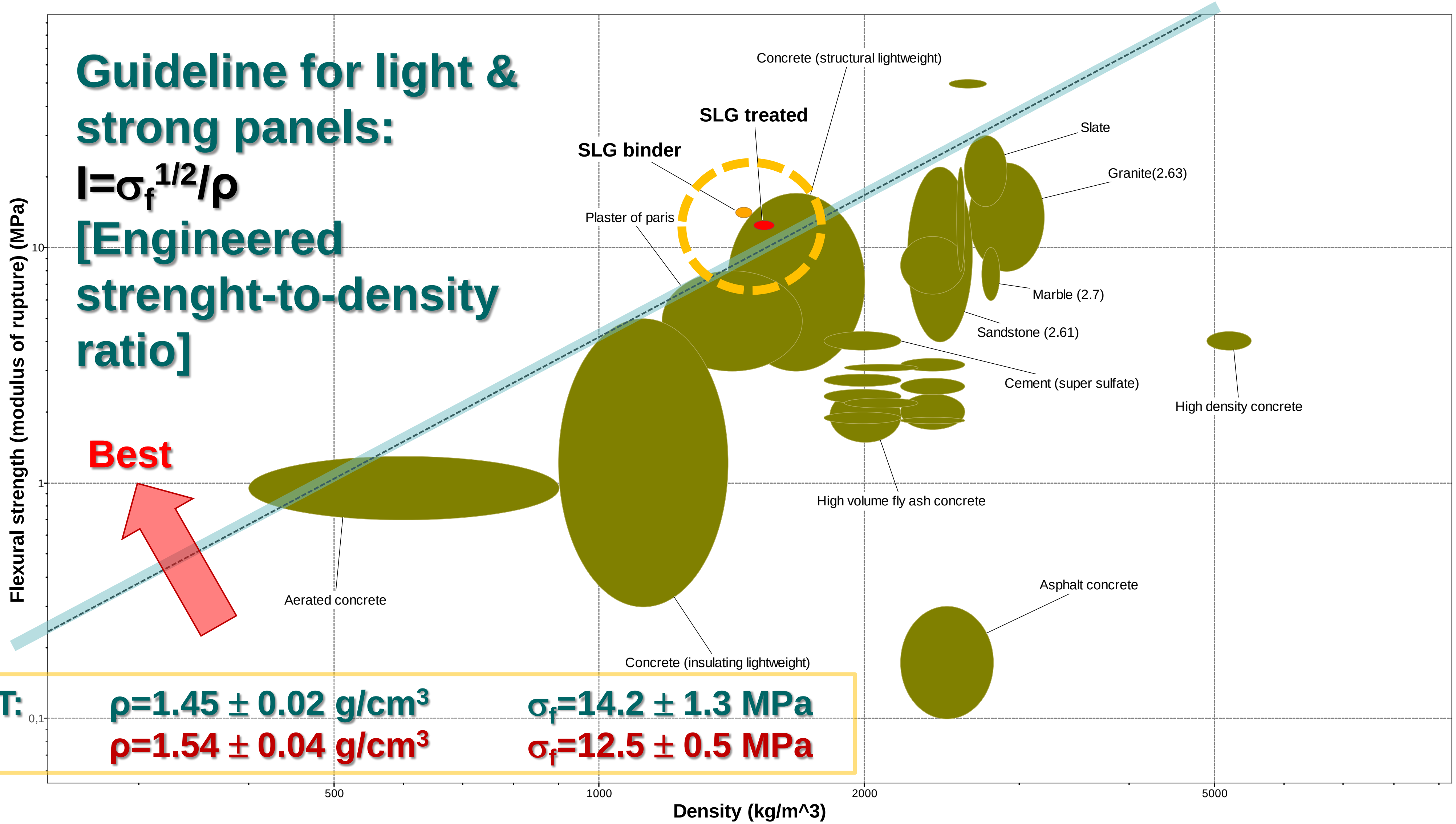
Different stabilization of sodium ions

Effect detected also by simple hand contact

Basic mechanical characterization

Glass-based gels comparable with concrete products

Modulus of Rupture (M.O.R.)



NT: $\rho = 1.45 \pm 0.02$ g/cm³ $\sigma_f = 14.2 \pm 1.3$ MPa

T: $\rho = 1.54 \pm 0.04$ g/cm³ $\sigma_f = 12.5 \pm 0.5$ MPa

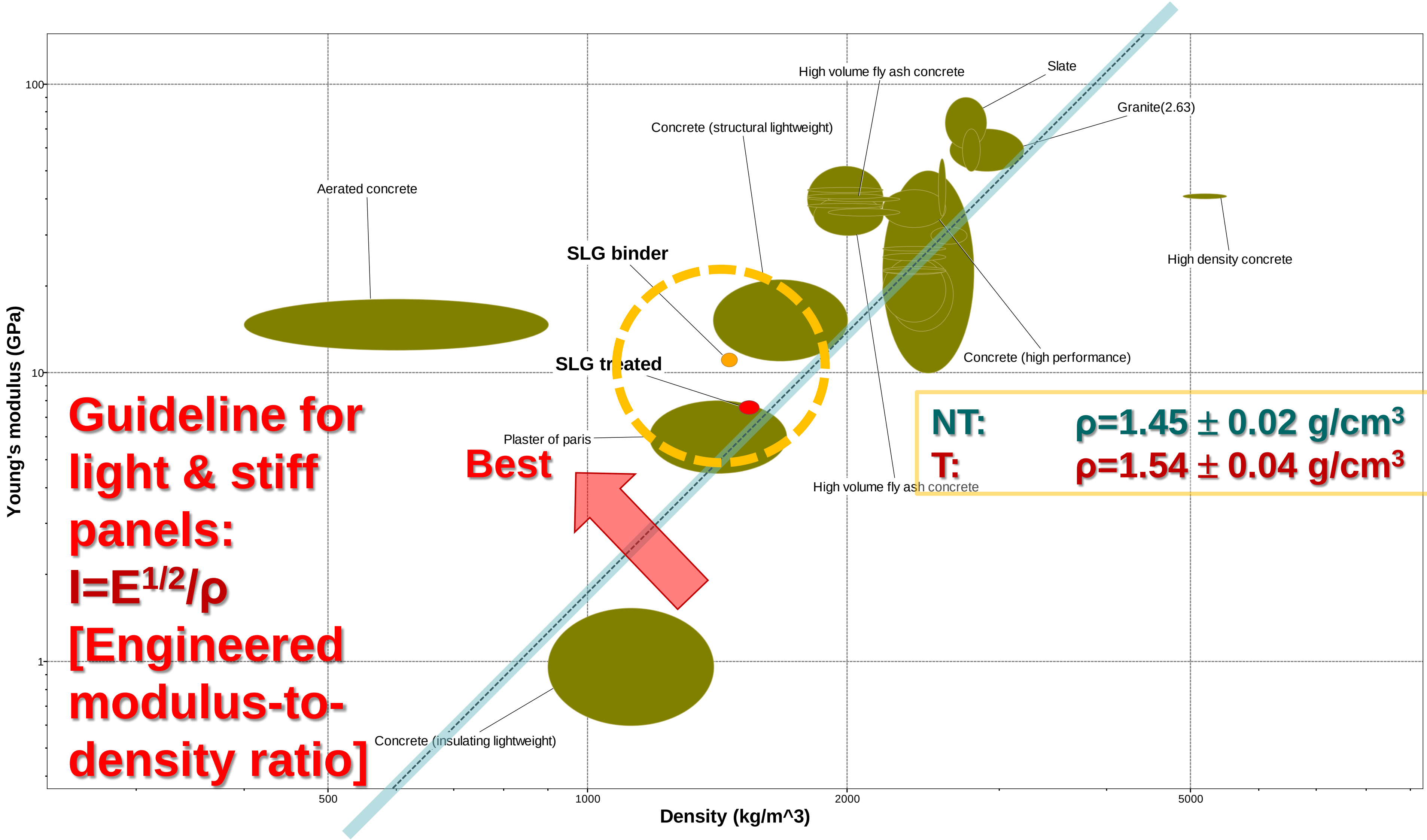
New cementitious materials comparing well with commercial ones in terms of strength

Graph and ref. data from CES (Cambridge Engineering Selector) EduPack 2019 [GrantaDesign, Cambridge, UK]

Basic mechanical characterization

Glass-based gels comparable with concrete products

Elastic modulus



Guideline for light & stiff panels: $I=E^{1/2}/\rho$ [Engineered modulus-to-density ratio]

New cementitious materials comparing well with commercial ones in terms of stiffness

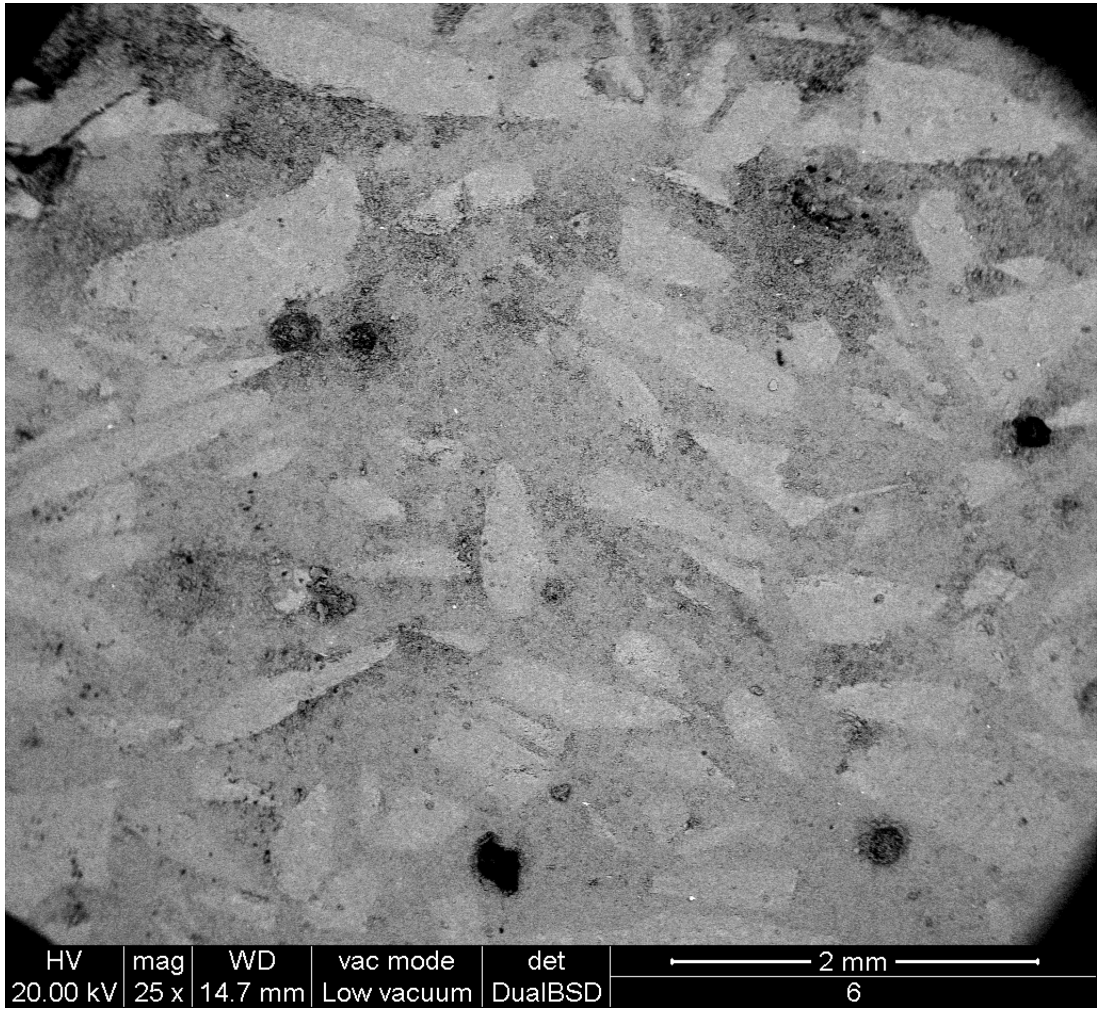
NT:	**$\rho = 1.45 \pm 0.02$ g/cm³**	**$E = 11.1 \pm 0.6$ GPa**
T:	**$\rho = 1.54 \pm 0.04$ g/cm³**	**$E = 7.56 \pm 0.4$ GPa**

Graph and ref. data from CES (Cambridge Engineering Selector) EduPack 2019 [GrantaDesign, Cambridge, UK]

Extension: dilution with coarse glass

Glass-based concrete: enhancing sustainability

50wt% coarse glass added

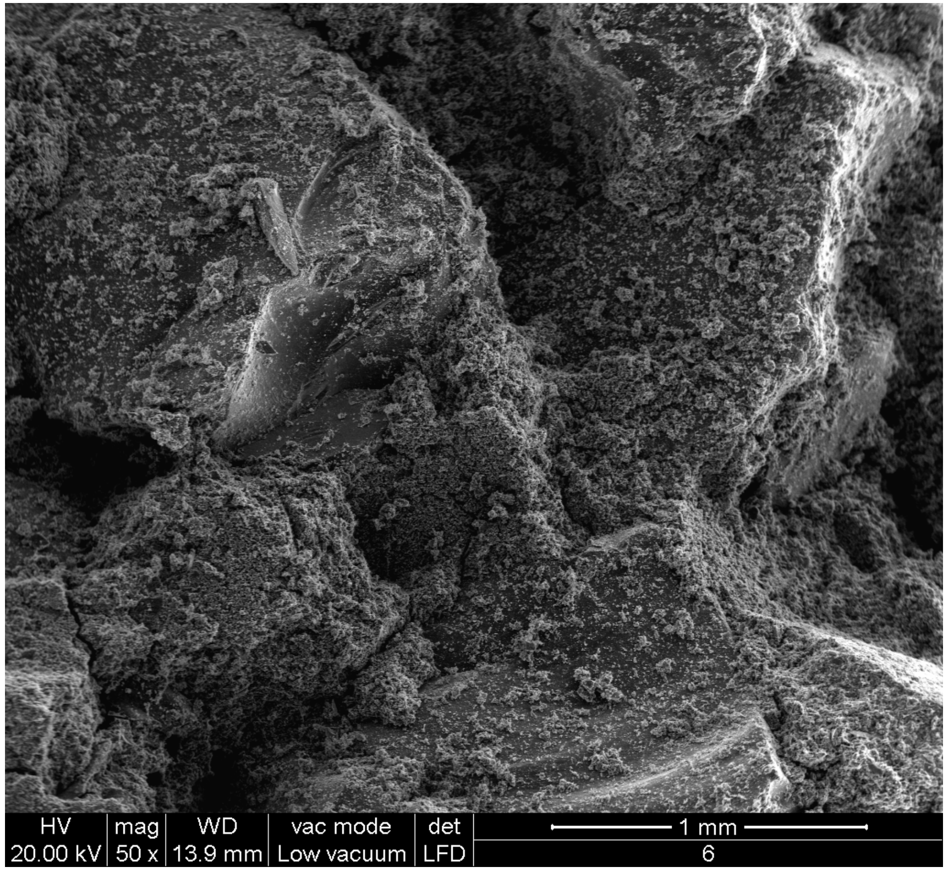


Binder from Acid Treated glass, polished surface

Coarse glass fragments (crushed and sieved in the interval: **300-1400 μm**) added as filler

Binder from Acid Treated glass, fracture surface: coarse fragments coated by gel

Crack passing at the interface, but mostly remaining in the gel



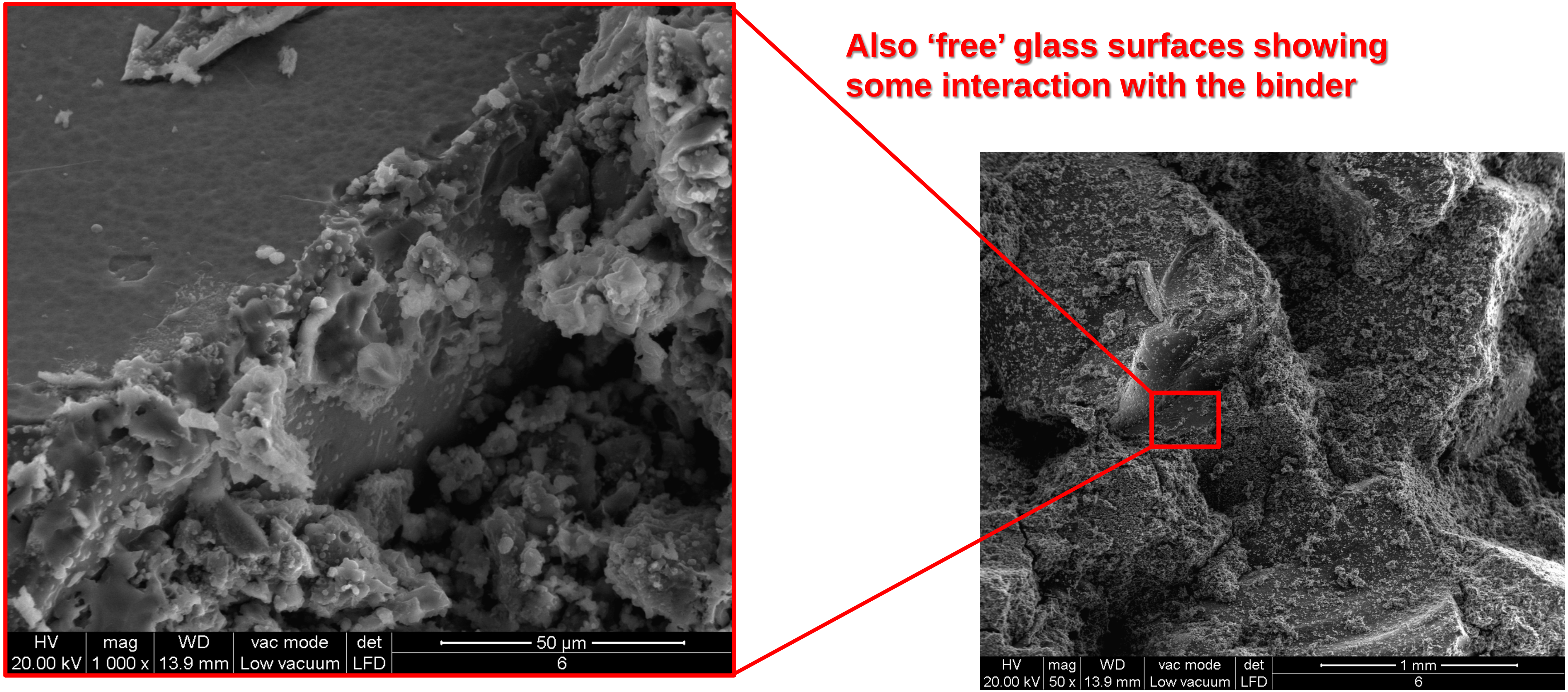
Overall $NaAlO_2$/SLG passing from **0.31** to **0.14** [0.31 g $NaAlO_2$/ 1g fine SLG/1.31 g coarse SLG]

Extension: dilution with coarse glass

Glass-based concrete: enhancing sustainability

50wt% coarse glass added

Also 'free' glass surfaces showing some interaction with the binder



Extensions

Are there more ‘geopolymer-oriented’ waste glasses than SLG?
Can be activation ‘lighter’ and simpler?
Can we get products with extended functionalities?

Changing glass

Back to pharmaceutical glass

Interesting for the content of B_2O_3 and Al_2O_3

Data in wt%

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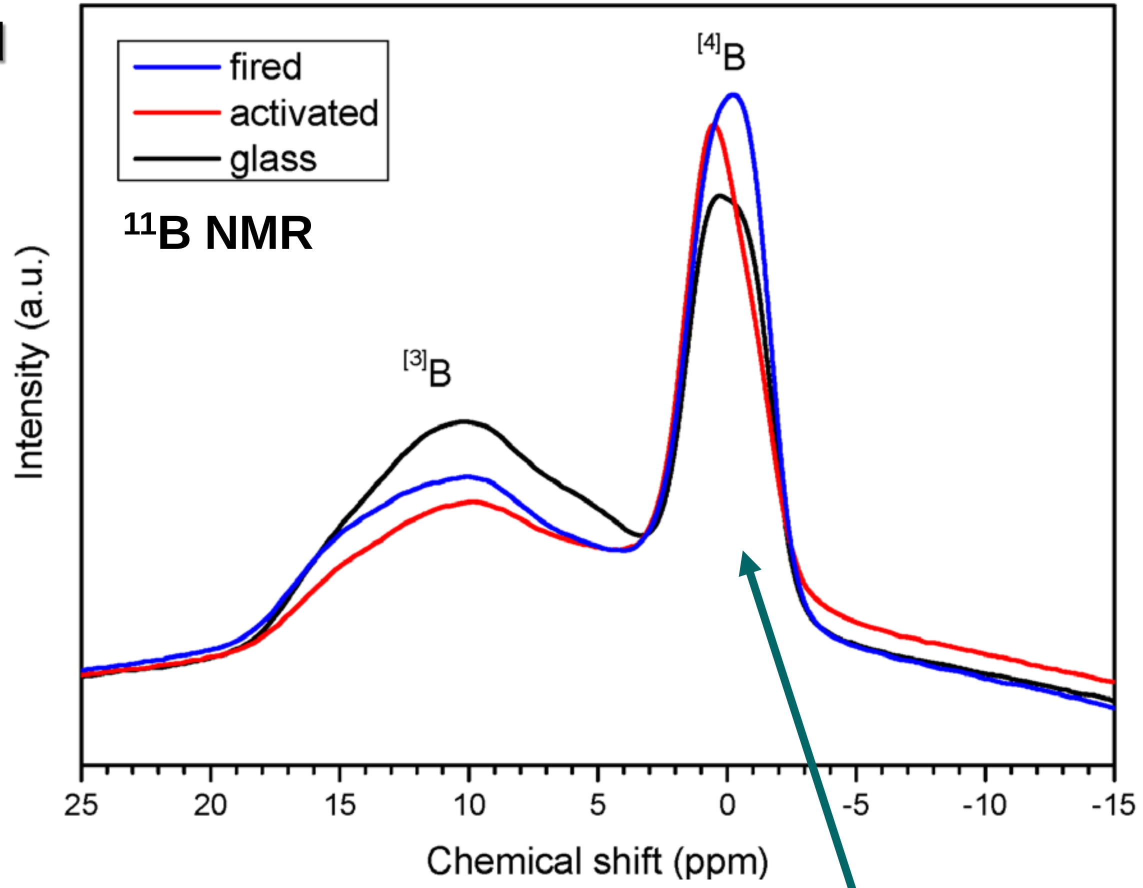
CaO	9.0	1
B_2O_3		12
Fe_2O_3	0.1	
TiO_2		
SrO		
others	0.5	
L.O.I.		

Glass courtesy of Nuova Ompi – Stevanato Group (Padova, Italy)

N-A-S-H gel verified also in 'weak' aqueous solutions containing 2.5 M NaOH

See **Rincon Romero et al. Materials 2018, 11(12), 2545**



Evidence of enhanced BO_4 units, trapping Na^+ ions [in gel, confirmed even after firing at 800 °C]

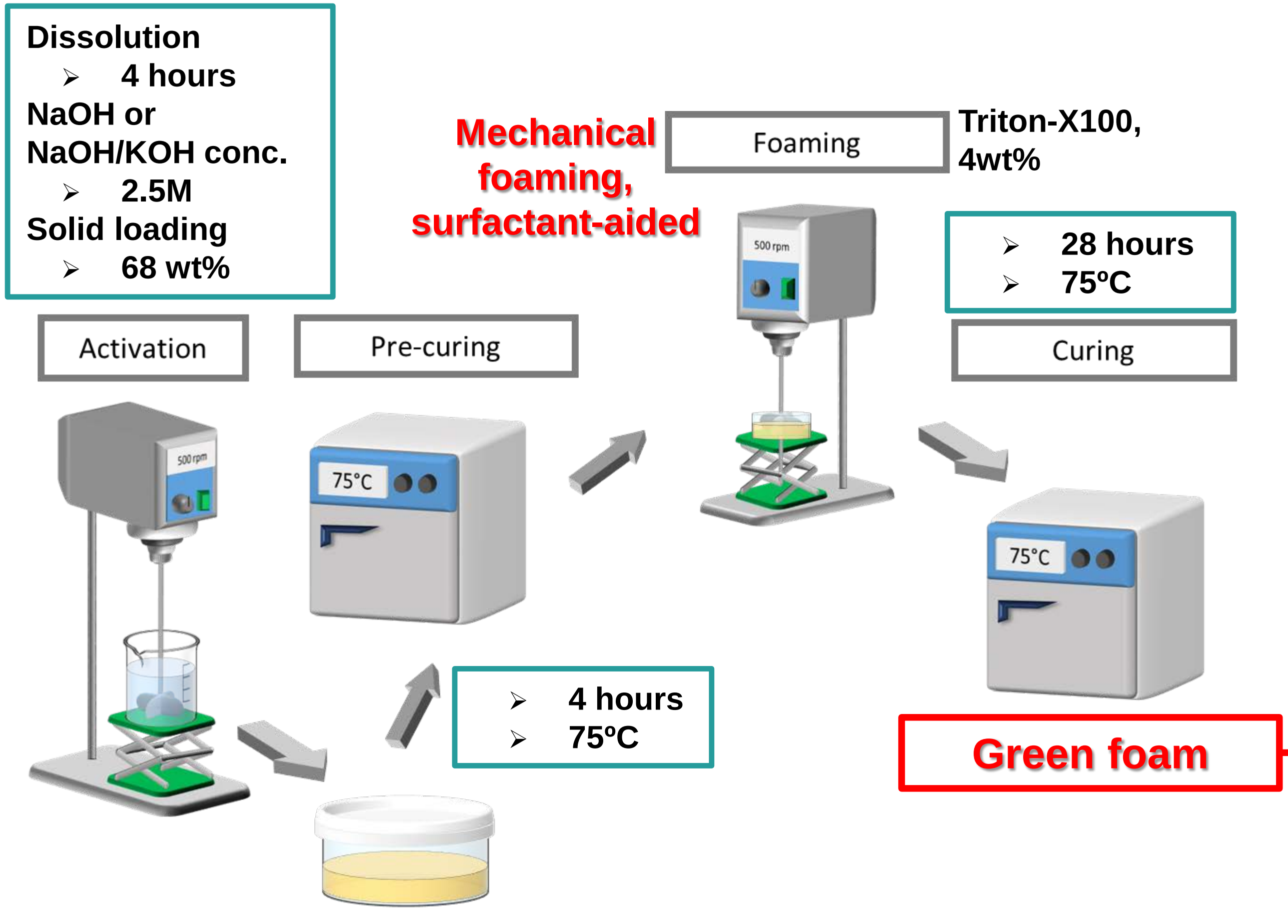
Glass foams

Mechanical foaming of alkali activated suspensions
Tuning with surfactant

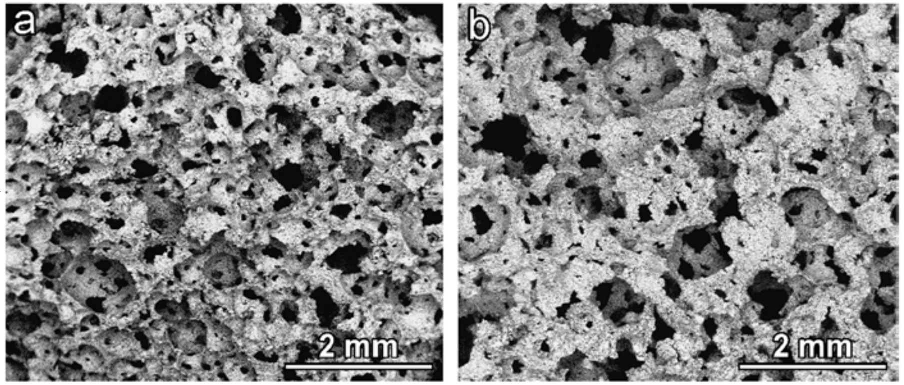
materials MDPI

Article

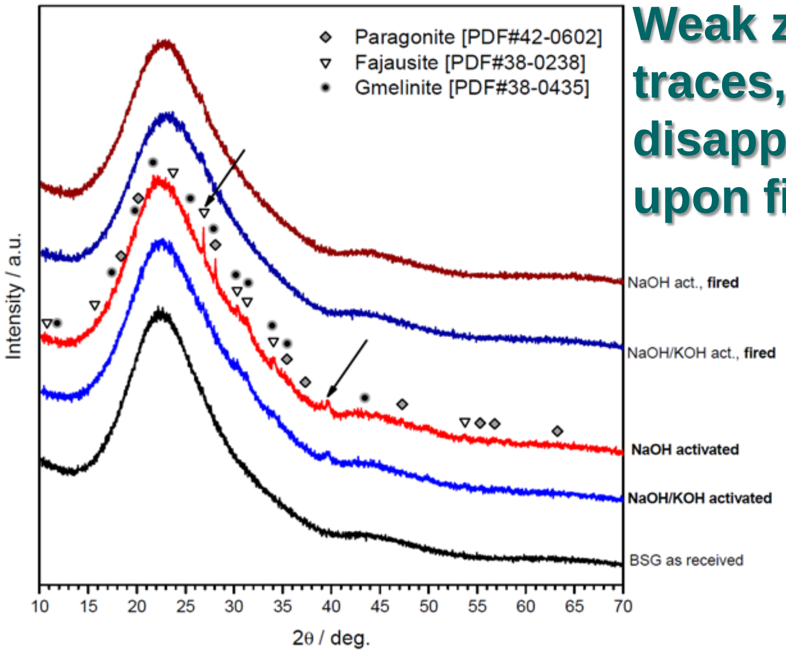
Extension of the 'Inorganic Gel Casting' Process to the Manufacturing of Boro-Alumino-Silicate Glass Foams



Particles bound by surface gel



NaOH   NaOH/KOH (50mol%-50mol%)



Weak zeolite traces, disappearing upon firing

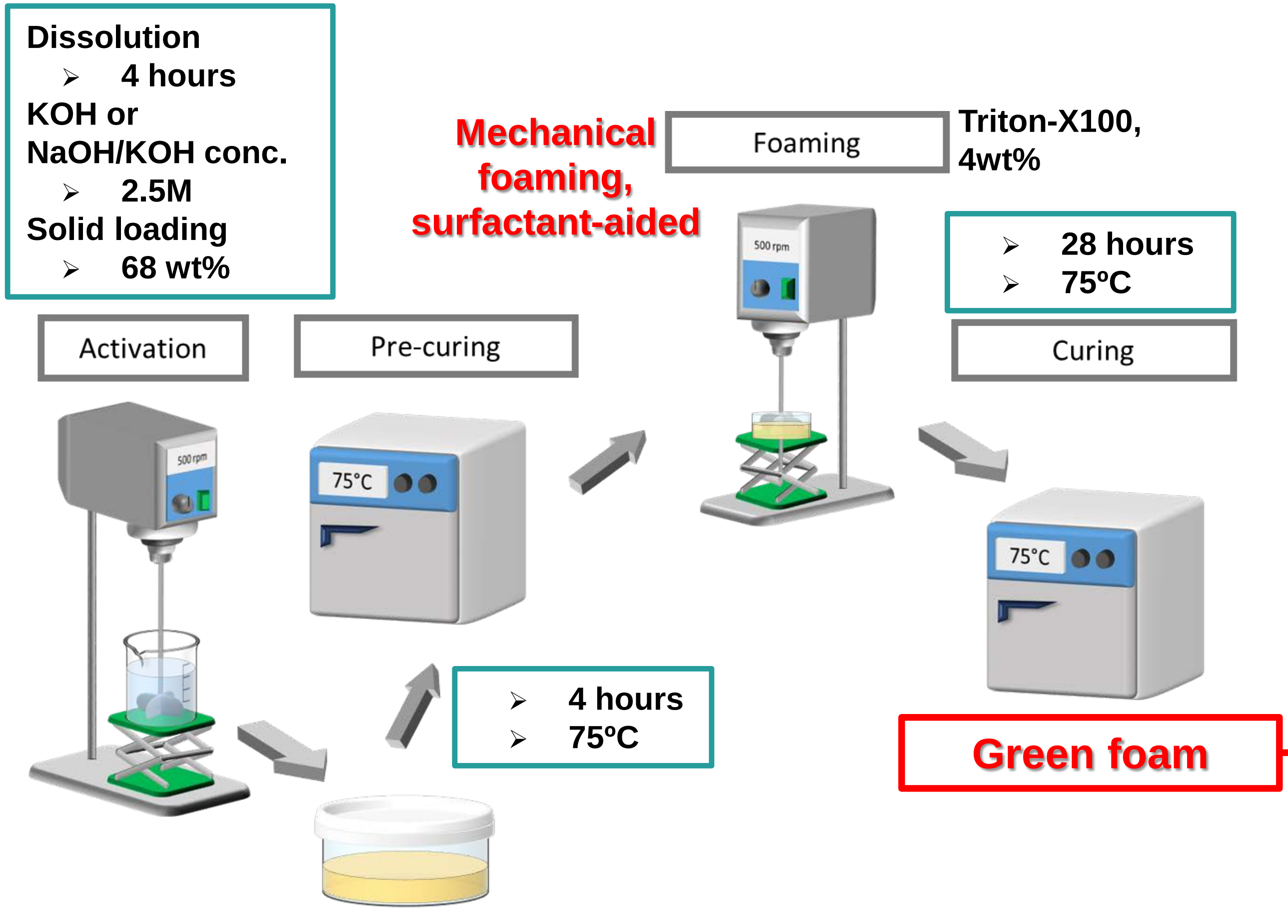
Glass foams

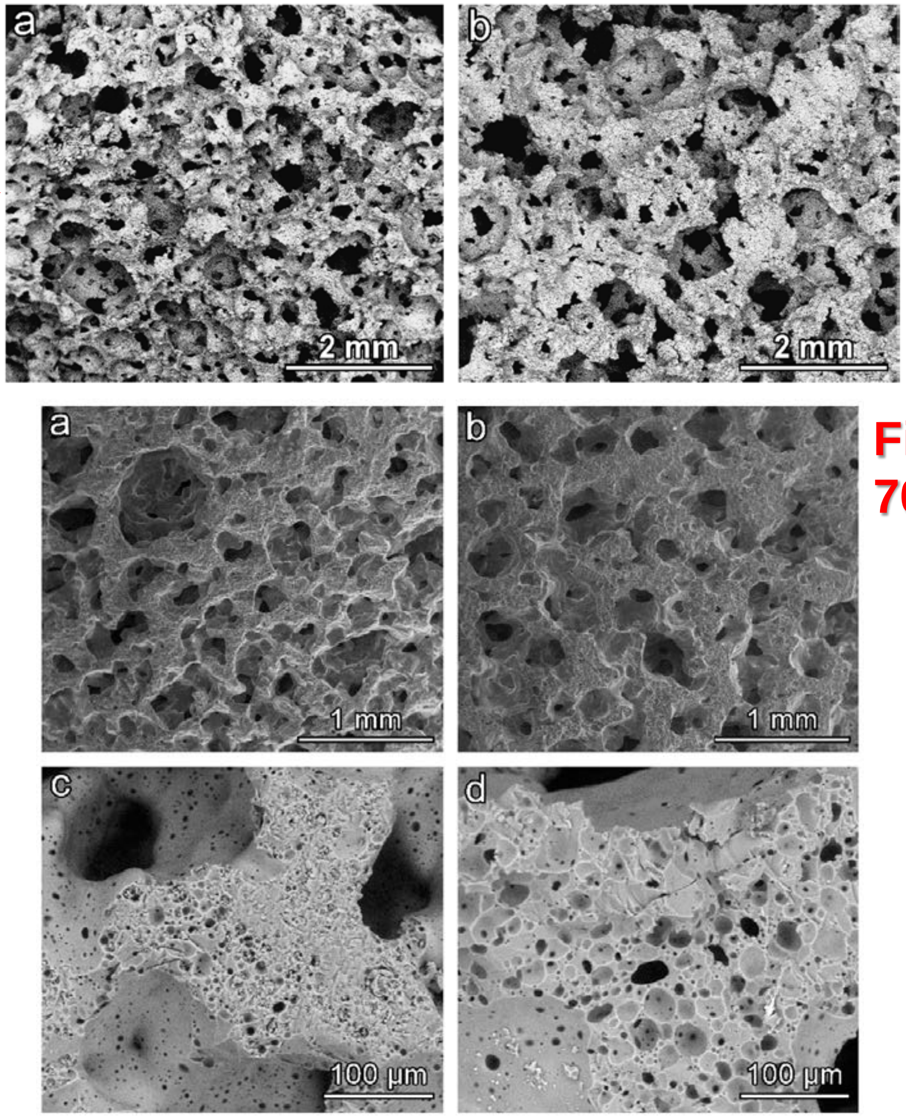
Mechanical foaming of alkali activated suspensions
Consolidation with surfactant

materials MDPI

Article

Extension of the 'Inorganic Gel Casting' Process to the Manufacturing of Boro-Alumino-Silicate Glass Foams





Fired at 700°C

From glass foams to…

Enhancing sustainability

Reduced surfactant content and temperature, even at T_g

Surfactant (%)	4			
Sintering Temperature (°C)	700			Green
ρ_{geom} (g/cm³)	0.87 ± 0.03			0.58 ± 0.02
$\rho_{apparent}$ (g/cm³)	1.88 ± 0.05			2.31 ± 0.02
ρ_{true} (g/cm³)	0.38 ± 0.03			0.25 ± 0.02
Total Porosity (vol %)	**61.6**			75.1
Open Porosity (vol %)	**53.7**			74.8
Closed Porosity (%)	**7.9**			0.3
σ comp (MPa)	**6.7 ± 0.4**			0.5 ± 0.1

Foams in the green state are weak
Consolidation after firing

From glass foams to…

Enhancing sustainability

Reduced surfactant content and temperature, even at T_g

Surfactant (%)	4			
Sintering Temperature (°C)	700	650	550	**Green**
ρ_{geom} (g/cm^3)	0.87 ± 0.03	0.70 ± 0.03	0.54 ± 0.03	0.58 ± 0.02
$\rho_{apparent}$ (g/cm^3)	1.88 ± 0.05	2.17 ± 0.03	2.38 ± 0.04	2.31 ± 0.02
ρ_{true} (g/cm^3)	0.38 ± 0.03	0.30 ± 0.04	0.23 ± 0.03	0.25 ± 0.02
Total Porosity (vol %)	61.6	**69.3**	77.4	75.1
Open Porosity (vol %)	53.7	**67.7**	77.2	74.8
Closed Porosity (%)	7.9	**1.7**	0.2	0.3
σ comp (MPa)	6.7 ± 0.4	**3.9 ± 0.4**	0.8 ± 0.2	0.5 ± 0.1

Foams in the green state are weak

Consolidation after firing at lower temperature: gel binder transforming into low-softening glass

From glass foams to…

Enhancing sustainability

Reduced surfactant content and temperature, even at T_g

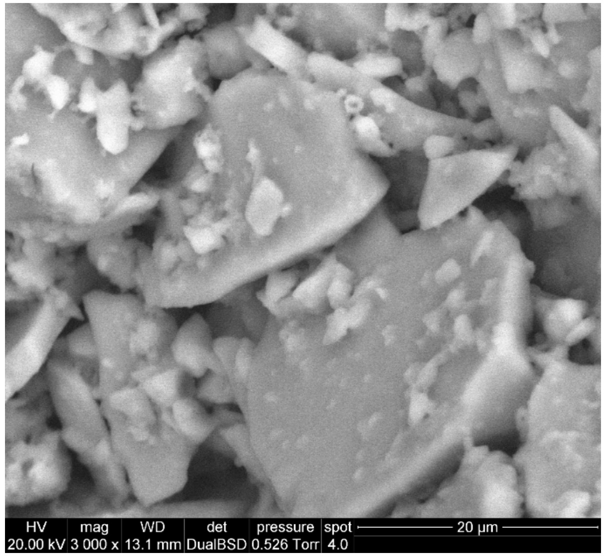
Surfactant (%)	4				2		
Sintering Temperature (°C)	700	650	550	**Green**	650	550	**Green**
ρ_{geom} (g/cm^3)	0.87 ± 0.03	0.70 ± 0.03	0.54 ± 0.03	0.58 ± 0.02	0.77 ± 0.03	0.64 ± 0.04	0.57 ± 0.03
$\rho_{apparent}$ (g/cm^3)	1.88 ± 0.05	2.17 ± 0.03	2.38 ± 0.04	2.31 ± 0.02	2.08 ± 0.04	2.36 ± 0.05	2.32 ± 0.04
ρ_{true} (g/cm^3)	0.38 ± 0.03	0.30 ± 0.04	0.23 ± 0.03	0.25 ± 0.02	0.34 ± 0.03	0.27 ± 0.04	0.24 ± 0.02
Total Porosity (vol %)	**61.6**	69.3	77.4	75.1	**66.4**	78.9	76.0
Open Porosity (vol %)	**53.7**	67.7	77.2	74.8	**62.8**	78.8	75.4
Closed Porosity (%)	**7.9**	1.7	0.2	0.3	**3.6**	0.1	0.6
σ comp (MPa)	**6.7 ± 0.4**	3.9 ± 0.4	0.8 ± 0.2	0.5 ± 0.1	**2.1 ± 0.2**	0.7 ± 0.1	0.7 ± 0.1

Confirmation with lower surfactant content

From glass foams to membranes

Enhanced strength with no foaming
Attention to binding phase

Surfactant (%)	4				*No surfactant*		
Sintering Temperature (°C)	700	650	550	**Green**	650	550	**Green**
ρ_{geom} (g/cm^3)	0.87 ± 0.03	0.70 ± 0.03	0.54 ± 0.03	0.58 ± 0.02	1.49 ± 0.03	1.41 ± 0.03	1.45 ± 0.04
$\rho_{apparent}$ (g/cm^3)	1.88 ± 0.05	2.17 ± 0.03	2.38 ± 0.04	2.31 ± 0.02	2.01 ± 0.03	2.19± 0.03	2.38 ± 0.03
ρ_{true} (g/cm^3)	0.38 ± 0.03	0.30 ± 0.04	0.23 ± 0.03	0.25 ± 0.02	0.59 ± 0.05	0.65 ± 0.05	0.61 ± 0.04
Total Porosity (vol %)	**61.6**	69.3	77.4	75.1	**41.2**	**34.7**	**39.0**
Open Porosity (vol %)	**53.7**	67.7	77.2	74.8	**31.3**	**31.9**	**39.0**
Closed Porosity (%)	**7.9**	1.7	0.2	0.3	**9.9**	**2.8**	**0.0**
σ comp (MPa)	**6.7 ± 0.4**	3.9 ± 0.4	0.8 ± 0.2	0.5 ± 0.1	**19.4 ± 0.4**	**16.4 ± 0.5**	**24.4 ± 0.6**

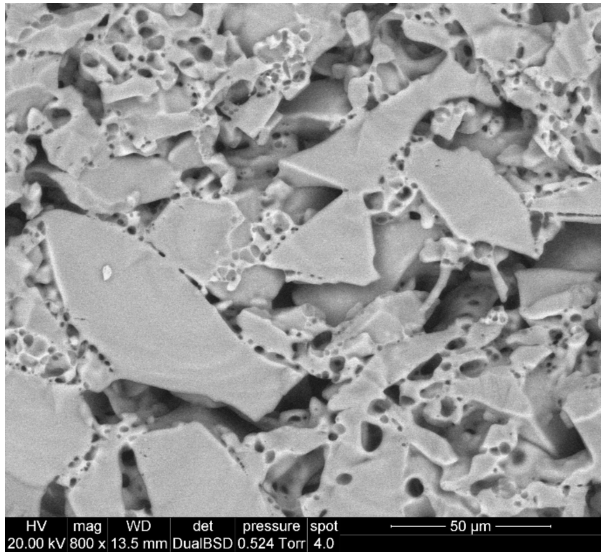


Green, unfoamed Gel binding particles

No foaming: more contact

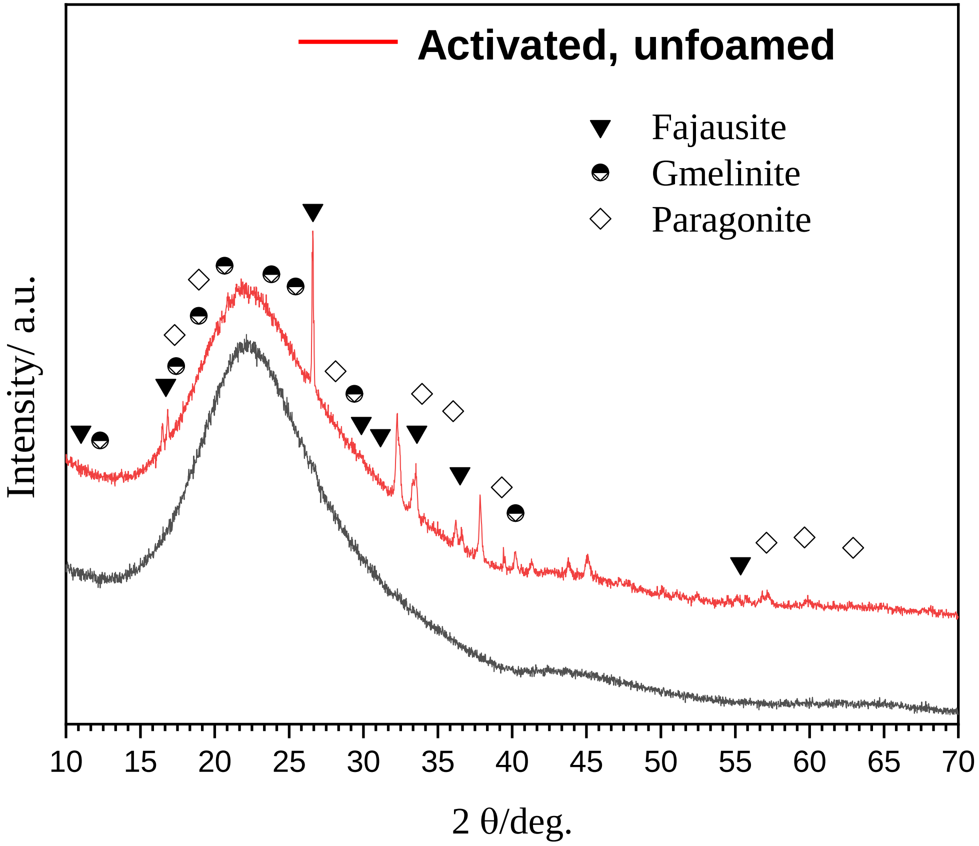
Fired at 550°C

No flow of glass, just transformation of gel

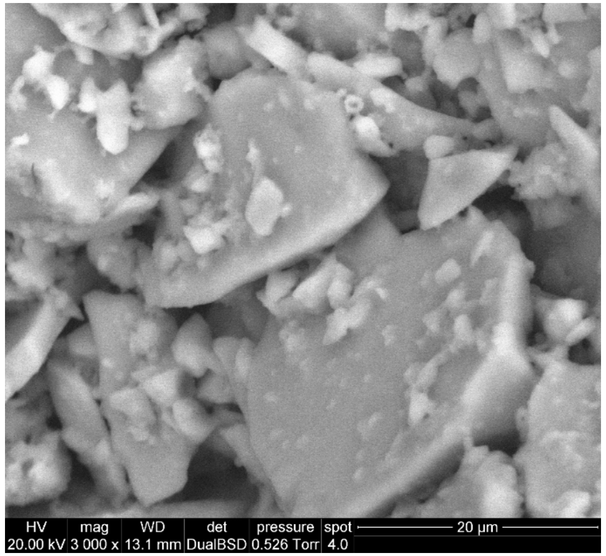


From glass foams to membranes

Enhanced strength with no foaming
Attention to binding phase



Enhanced zeolite formation → Use in water purification



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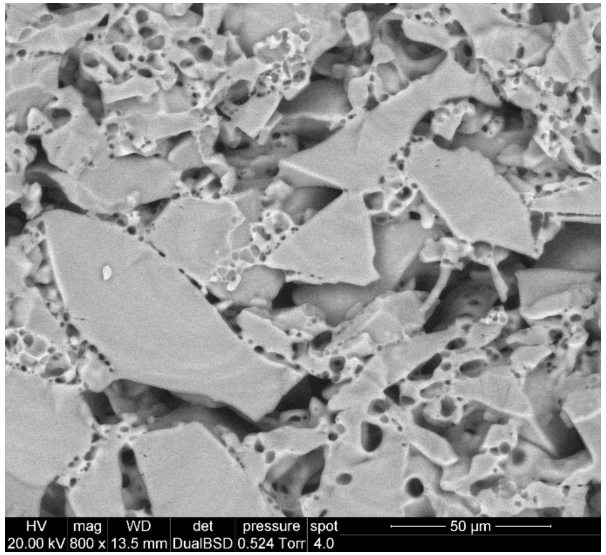
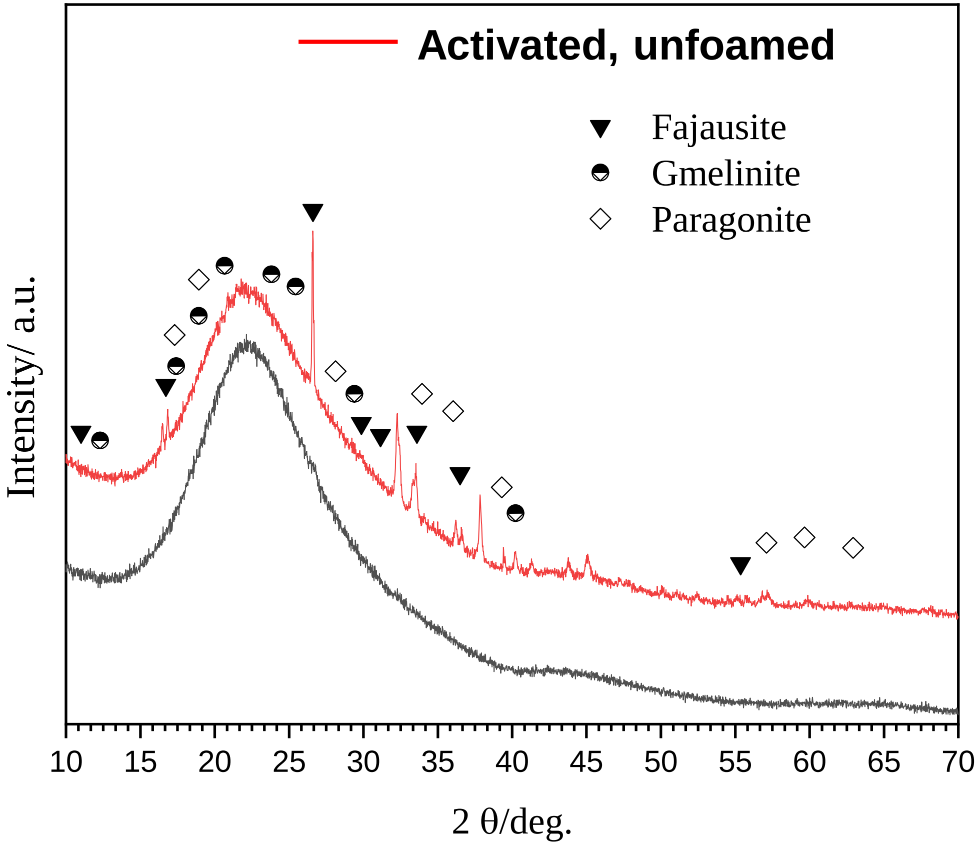
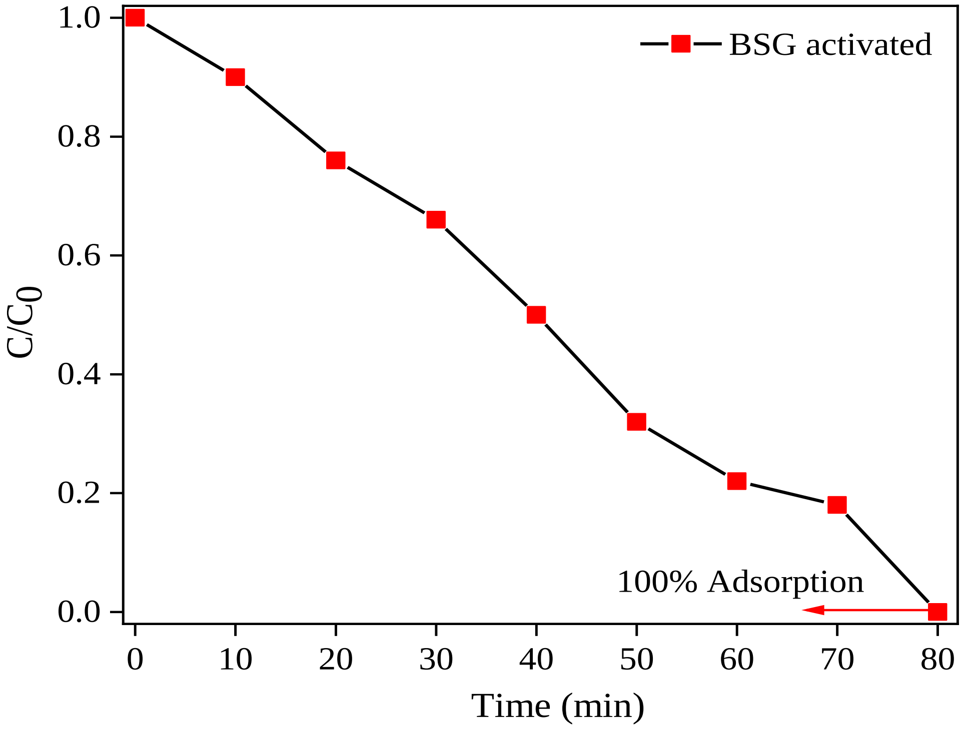


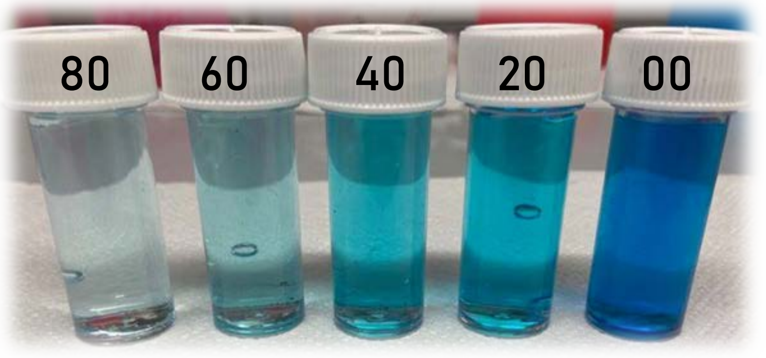
From glass foams to membranes

Enhanced strength with no foaming
Attention to binding phase



Enhanced zeolite formation → Use in water purification





Application in Dye Removal from Water

Model Dye: Methylene Blue, Initial concentration: 10mg/mL

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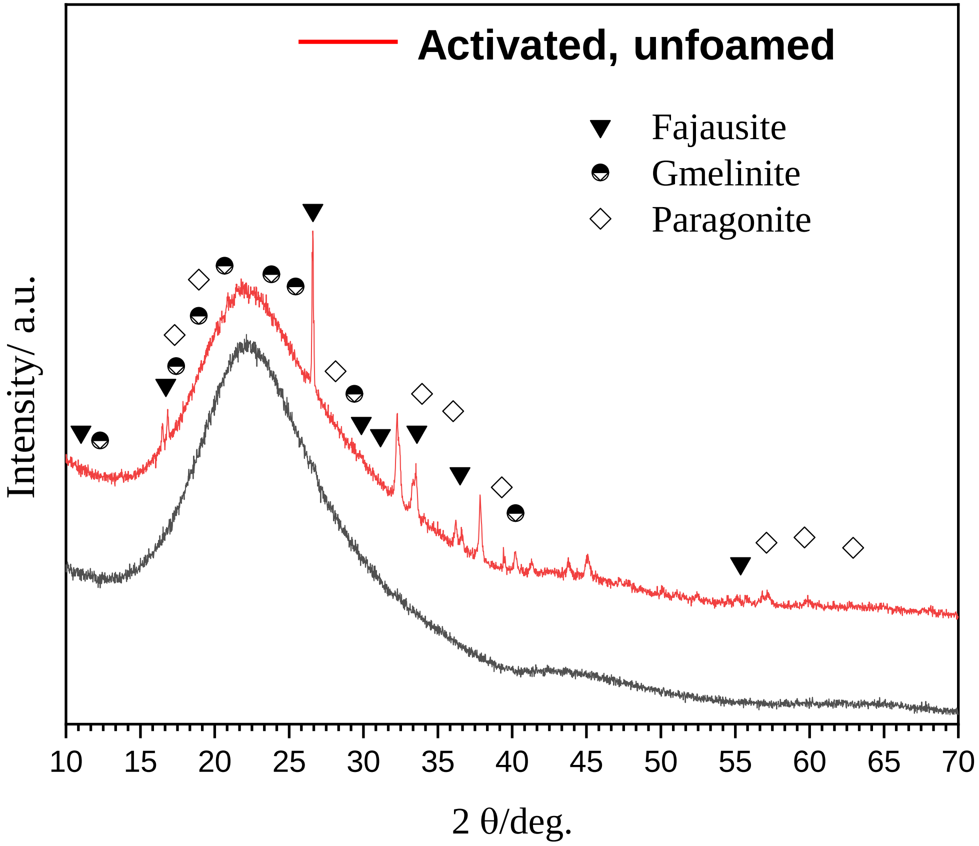
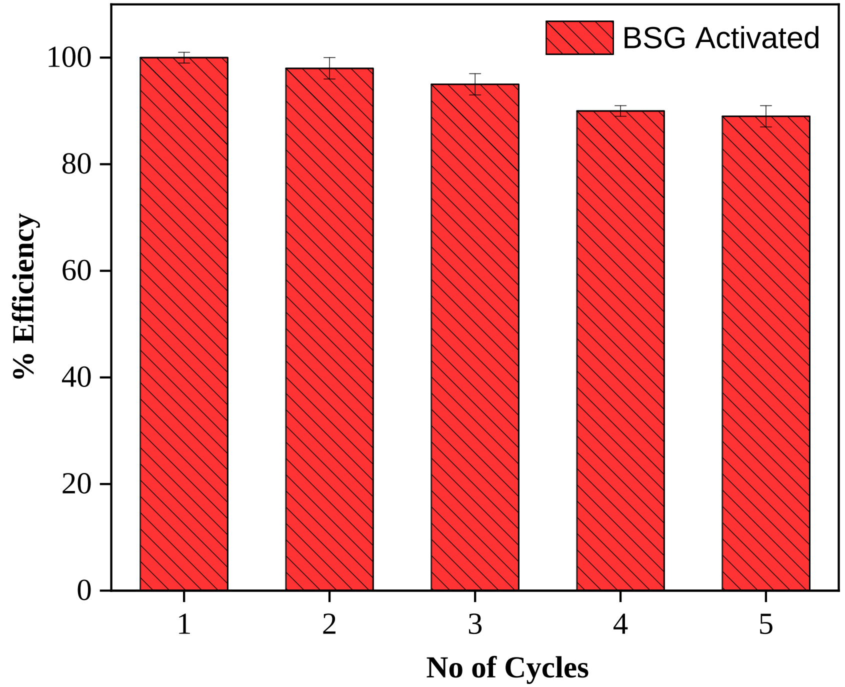
From glass foams to membranes

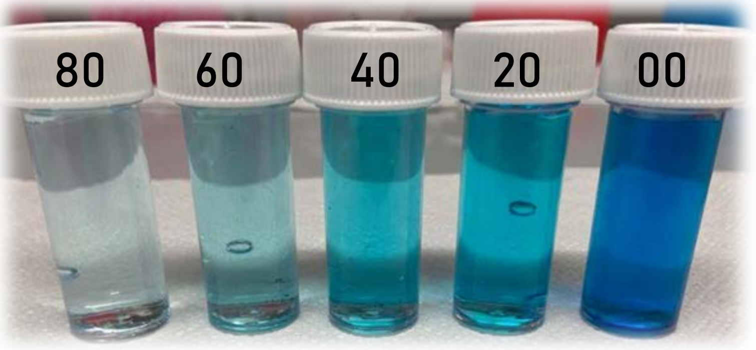
Enhanced strength with no foaming
Attention to binding phase

In progress

Enhanced zeolite formation → Use in water purification







Application in Dye Removal from Water

Model Dye: Methylene Blue, Initial concentration: 10mg/mL

Reusable sorbents [1 cycle: 80 min adsorption + dye extraction by centrifugation]

Back to SLG

BSG ‘naturally’ prone to zeolitization
But SLG can be combined with Al_2O_3 rich waste…

Chemical Component	Rock Wool (RW)
CaO	17.4
SiO_2	40.4
Al_2O_3	15.8
Fe_2O_3	9.2
Na_2O	1.4
K_2O	0.4
MgO	12.6
P_2O_5	0.1
TiO_2	0.8
SO_3	n.d
Cl	n.d

J. Yliniemi et al., Utilization of Mineral Wools as Alkali-Activated Material Precursor. *Materials* 9 (2016) 312.

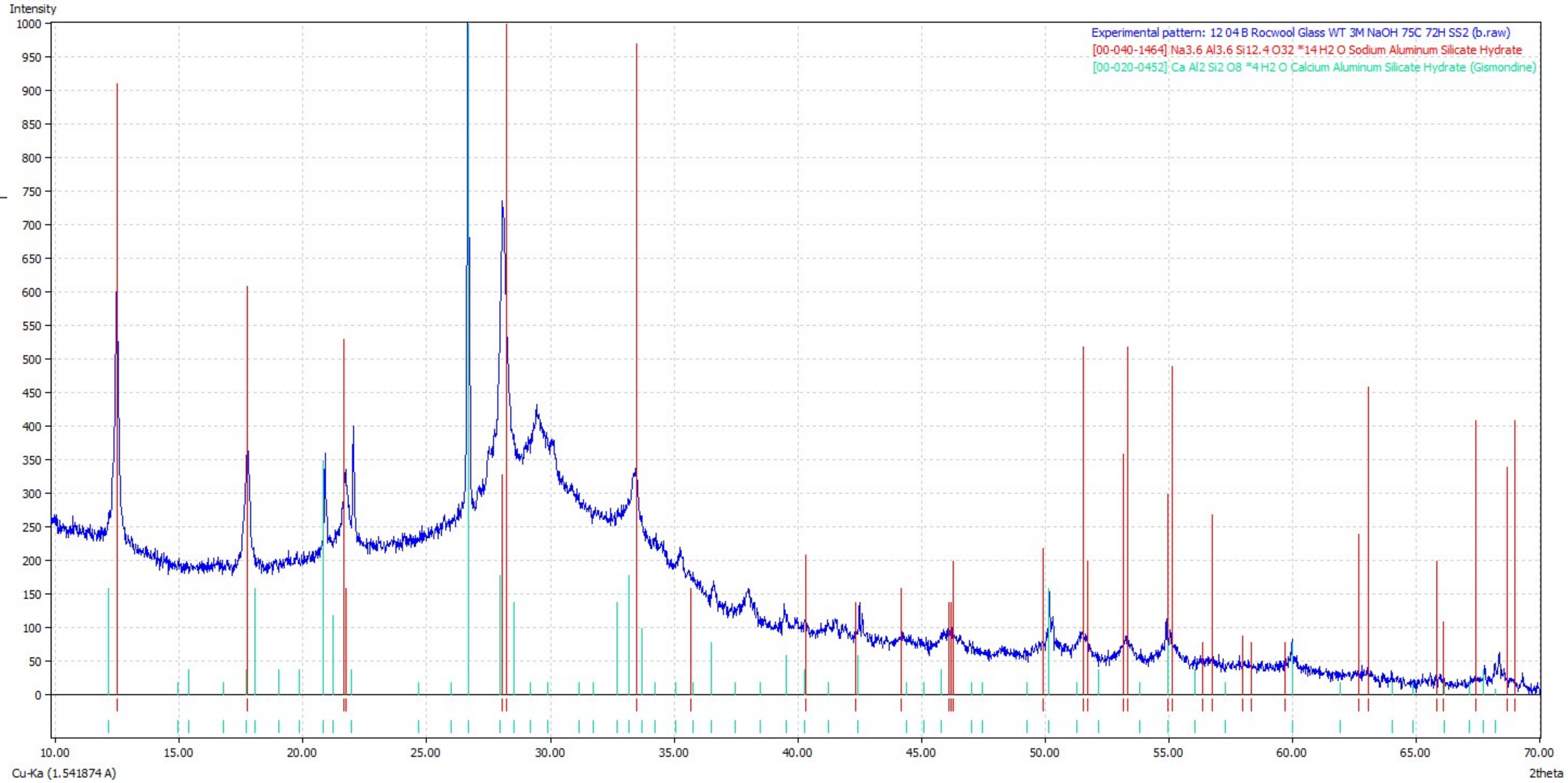
Raw materials: 50 wt% SLG, 50 wt% RW (all amorphous)

In solution 3M NaOH (30 min), 3d at 75 °C

Liq/Sol=0.53

Activation: formation of zeolites

Sodalite (Na-based) and Gismondine (Ca-based)



Back to SLG: cold consolidation and new foams

While BSG is 'naturally' prone to zeolitization
SLG can still be combined with Al_2O_3 rich waste…

Chemical Component	Rock Wool (RW)
CaO	17.4
SiO_2	40.4
Al_2O_3	15.8
Fe_2O_3	9.2
Na_2O	1.4
K_2O	0.4
MgO	12.6
P_2O_5	0.1
TiO_2	0.8
SO_3	n.d
Cl	n.d

J. Yliniemi et al., Utilization of Mineral Wools as Alkali-Activated Material Precursor. *Materials* 9 (2016) 312.

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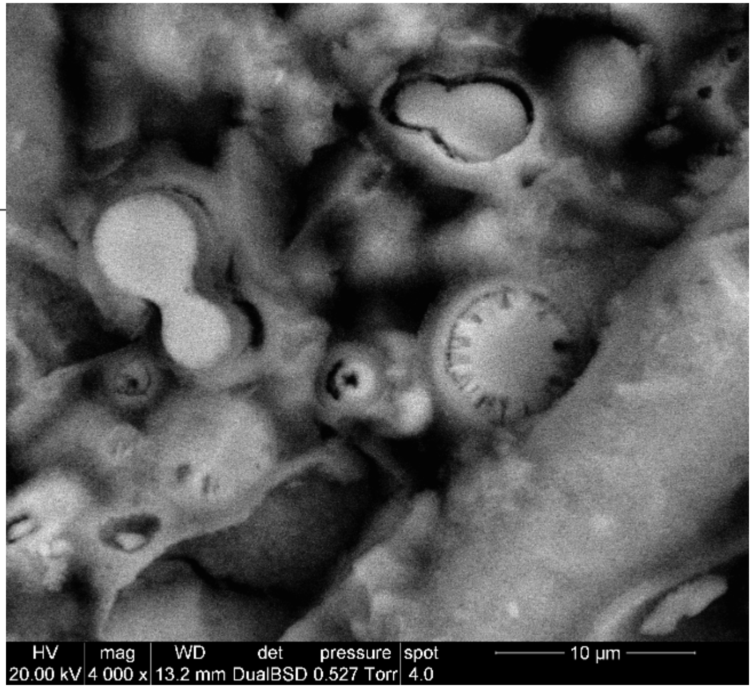
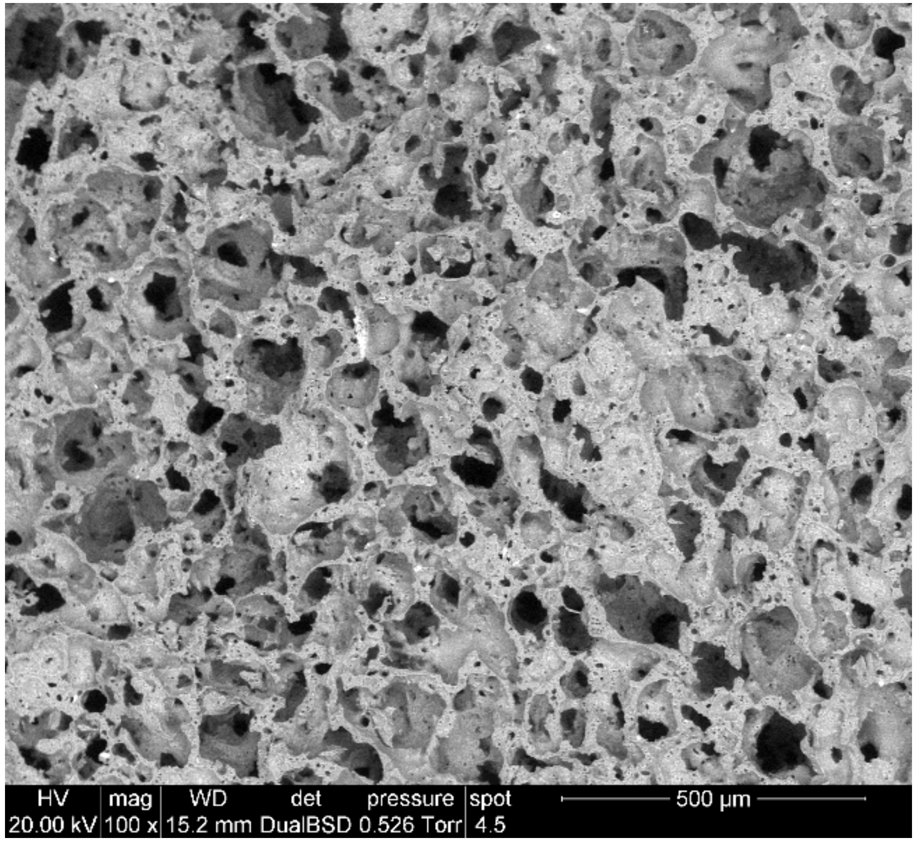
Liq/Sol=0.53
Activation: formation of zeolites
Sodalite (Na-based) and Gismondine (Ca-based)

In progress



After drying
Sample surviving boiling test
[geopolymer-like]



After firing at 800 °C: glass-ceramic foam
Foaming by decomposition of hydrated binding phase

Concluding remarks

…and future perspectives

Discarded glasses expressing **great potential for the obtainment of stable inorganic gels**

Systems to be adjusted by:

- ***Activators***: Aluminates significant in yielding AlO_4 units
- ***Selection of glasses***: **some glasses are inherently prone to the formation of zeolite-like gels**
- **Secondary waste:** attention to Al_2O_3-rich waste

Other features:

- **Development of porous bodies**: exploration of pore generation at the early stage of gelation (by intensive **mechanical stirring**) or **decomposition of binding phase**
- **Sorbents: simplified approach, focus on zeolite phases**

Acknowledgements

Funding and support

- **European Community's Horizon 2020 Programme through a Marie Skłodowska-Curie Innovative Training Network ('CoACH", g.a. no. 642557) http://www.coach-etn.eu**
- European Community's Horizon 2020 Programme through H2020-WIDESPREAD-01-2016-2017-TeamingPhase2 project ('**FunGLASS**", g.a. no. 739566) **http://www.funglass.eu/**

COACH European Training Network

FunGlass

European Commission | Horizon 2020 European Union funding for Research & Innovation

MANY THANKS FOR YOUR ATTENTION!

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http://www.dii.unipd.it/bernardo