Alkali-bonded composites for thermal and acoustic insulation

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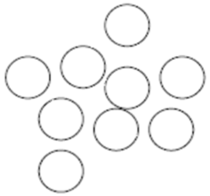
Geopolymers = Alkali Bonded Ceramics

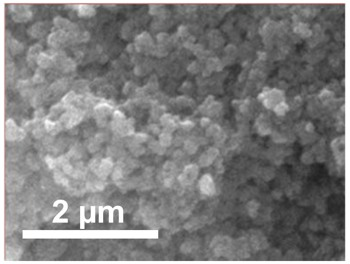
This technology allows the production of ceramic-like materials and composites by using simple and low temperature processes.



$Al_2O_3 \cdot xSiO_2$ powder

$M_2O \cdot xSiO_2$ solution

→



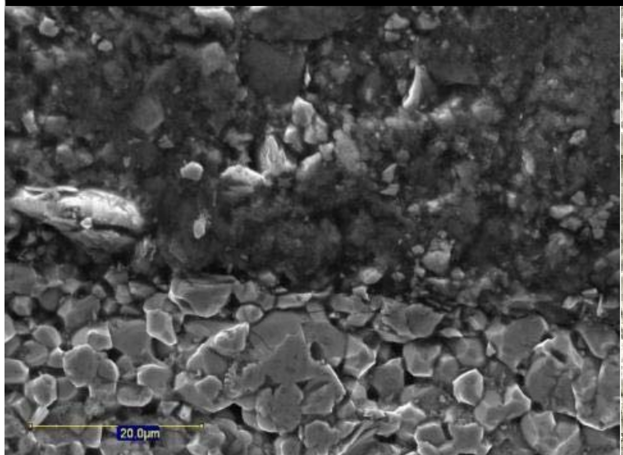
Processing T: RT-120°C

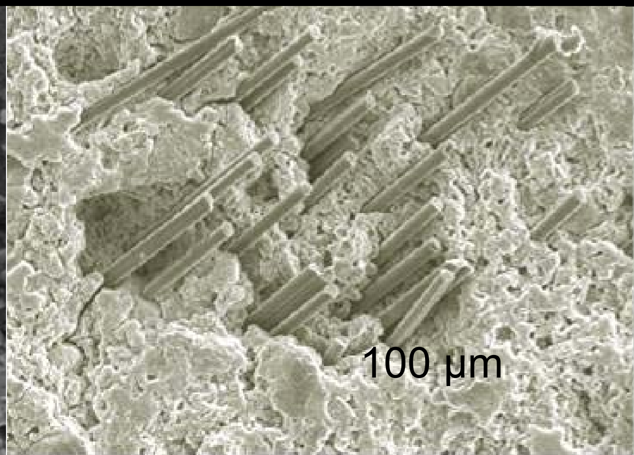
Near-net-shaping:

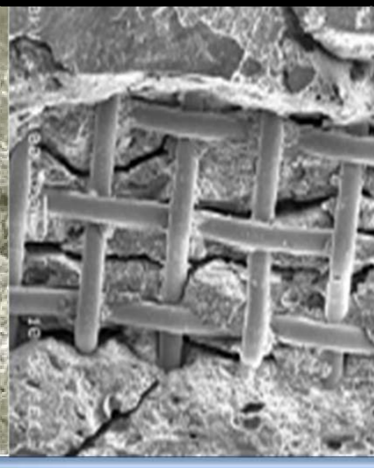
casting in mould, brushing, etc.

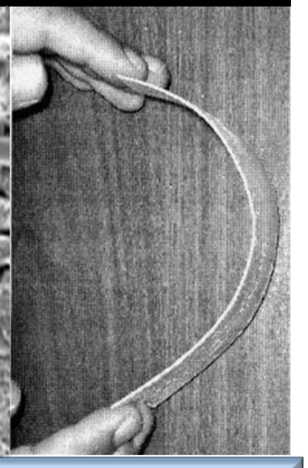
Nano-precipitates act as a glue sticking the added fillers to produce ALKALI BONDED COMPOSITES

Powders (SiC, ZrO2….) ⇒ refractoriness, CTE	Fibers (carbon, glass) ⇒ mechanical properties, heat transfer	Metals ⇒ ductility	Organics ⇒ flexibility







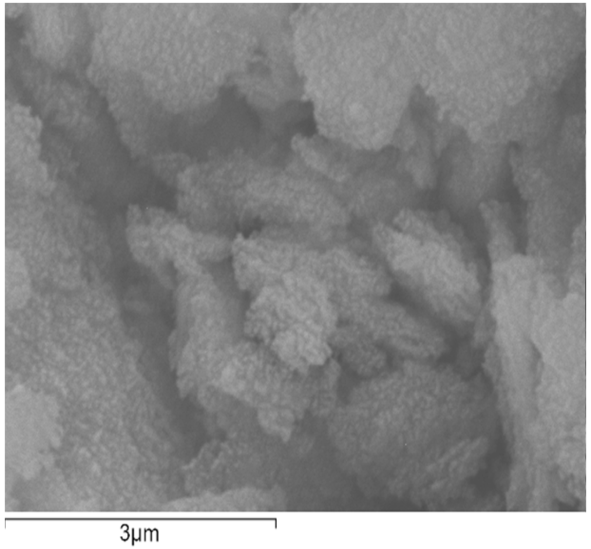


Fire proof, heat resistant composites

- Foams
- Binder and paints
- Bulk materials
- Fiber composites

Geopolymers insure thermal protection up to 1200°C depending on the composition. The completely inorganic nature and the absence of water in structure (as opposed to hydraulic cements) makes them particularly resistant to heat and fire

- Excellent burn-through fire resistance
- No ignitability
- No flammability
- No combustion gases
- No toxicity
- No smoke emanation
- No heat release
- No combustion gas generation
- Infinite time to flashover
- No explosion

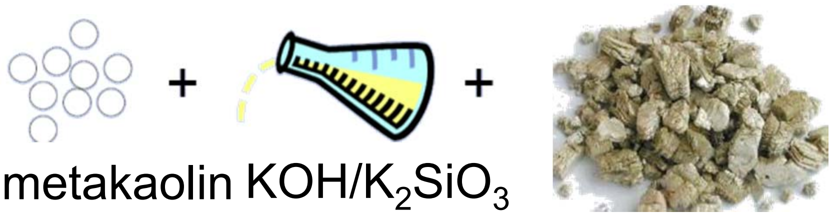


Water does not enter into the geopolymeric framework, but it gives rise to a steric hindrance and acts as a pore forming agent upon its removal during setting

Examples Overview

metakaolin KOH/K_2SiO_3 SiC

metakaolin KOH/K_2SiO_3 Ceramic wastes



metakaolin or alumina KOH/K_2SiO_3 vermiculite

alkali actived binder, biosoluble fiber, forming agent

Inorganic *in situ* foam formation

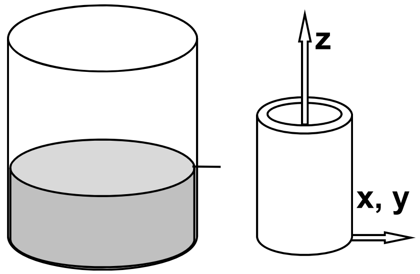
Gas evolution leads to foamed architectures when the viscosity of the slurry contemporary increases and the material consequently consolidates.

Redox reaction with H_2 evolution

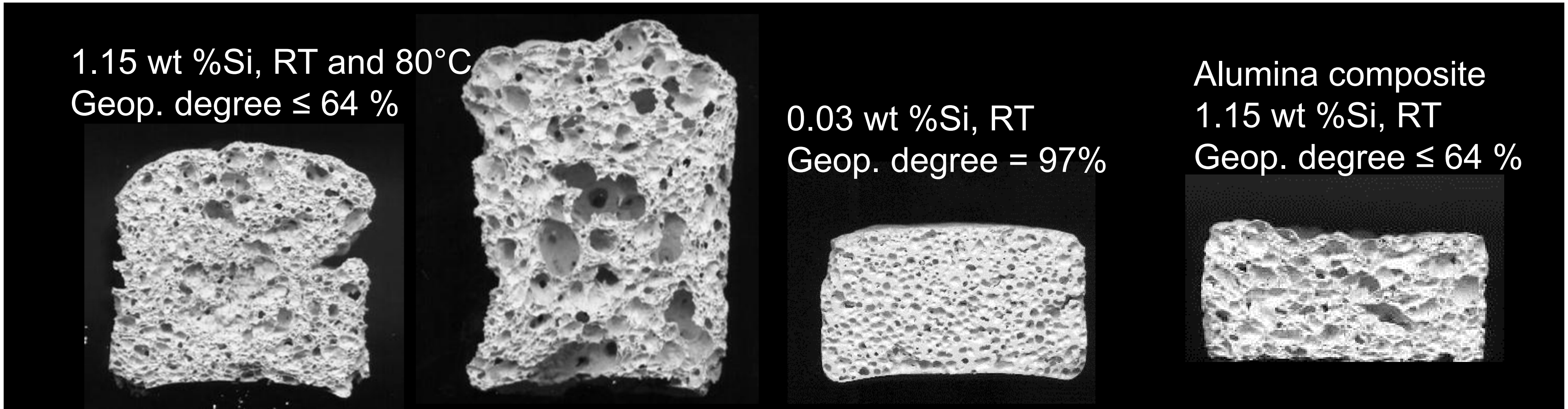
$Si^0 \rightarrow Si^{4+} + 4e^-$ (1)

$4H_2O + 4e^- \rightarrow 2H_2 + 4OH^-$ (2)

$4H_2O + Si_0 \rightarrow 2H_2\uparrow + Si(OH)_4$ (3)



Water consuming and exothermic reaction $\Delta H = -314$ kJ/mol at 25°C

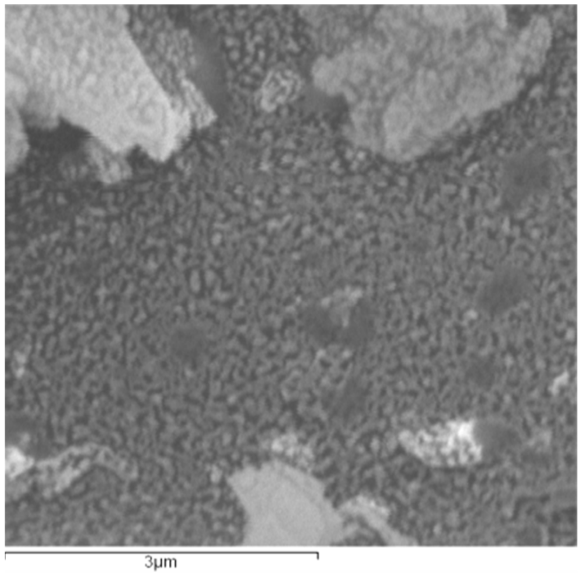


Alkali Bonded SiC 90 wt% Based Foams

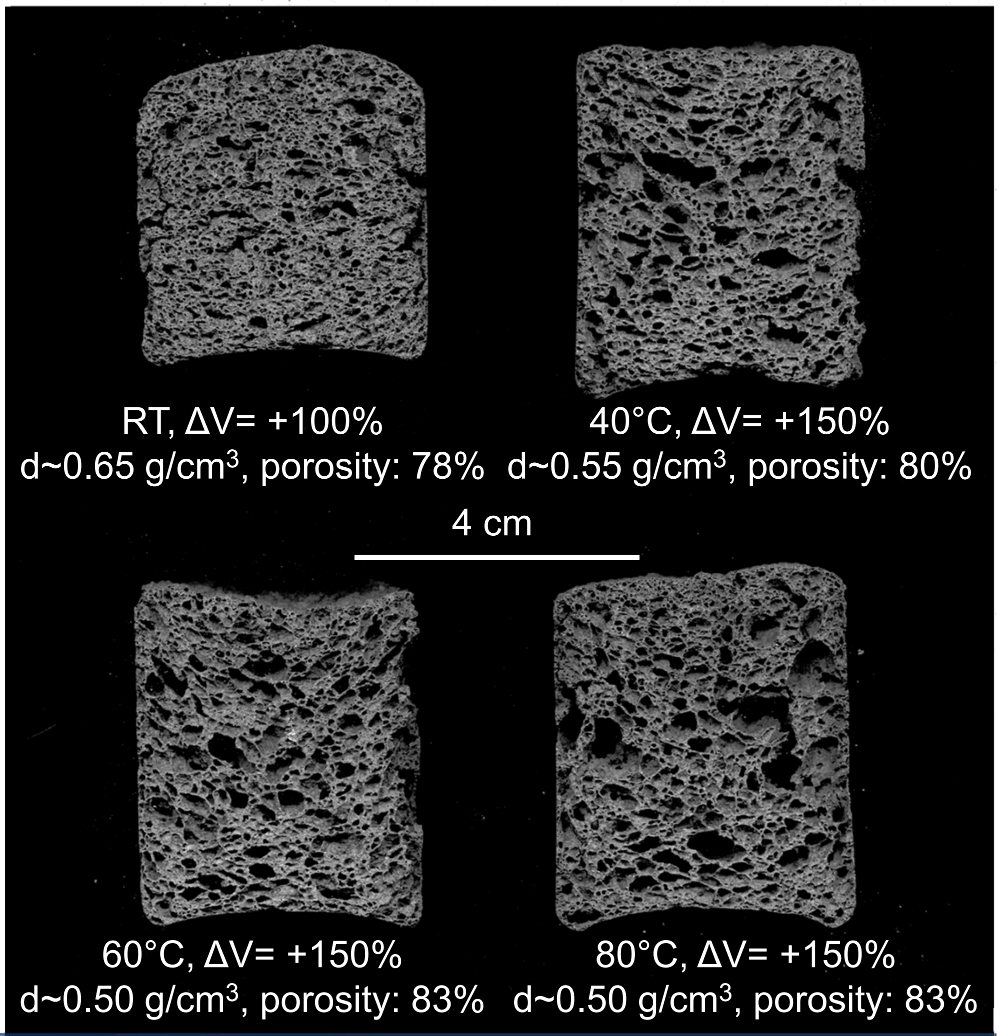
Foaming agent: Si^0 traces intrinsically contained in all SiC powders

α-SiC grade 100F St. Gobain,
s.s.a.: 0.58 m^2/g, 0.9 vol% Si.

Nano-precipitates easily formed on SiC surface because of the oxygen rich layer similar to the amorphous silica



Mechanical mixing at 100 rpm,
Setting at 24h at RT-80°C in open mould + 24h at 80°C



Alkali Bonded SiC 90 wt% Based Paints

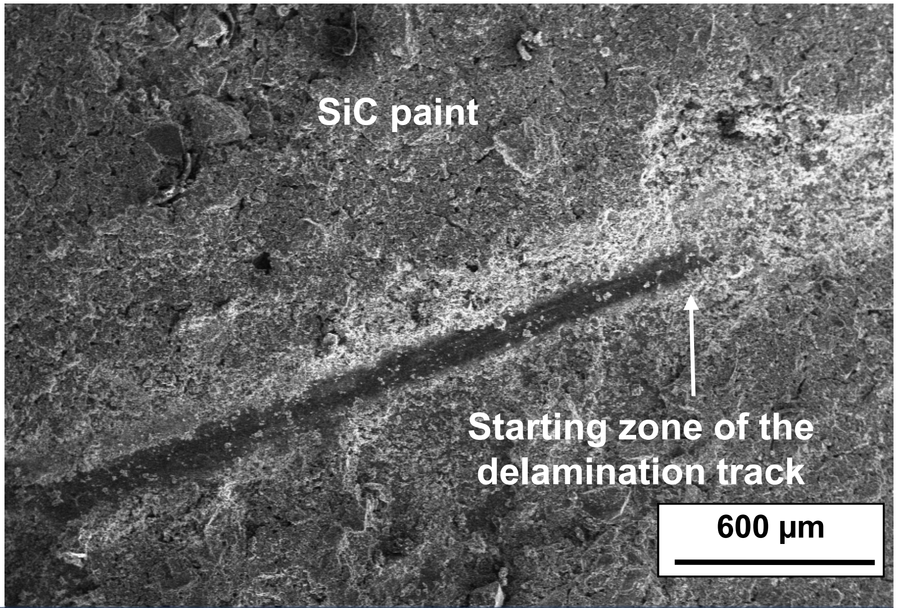
When fast setting takes place,
Si^0 redox reaction does not occur

200 µm thick coatings deposited onto metallic and ceramic substrates by brushing quickly harden

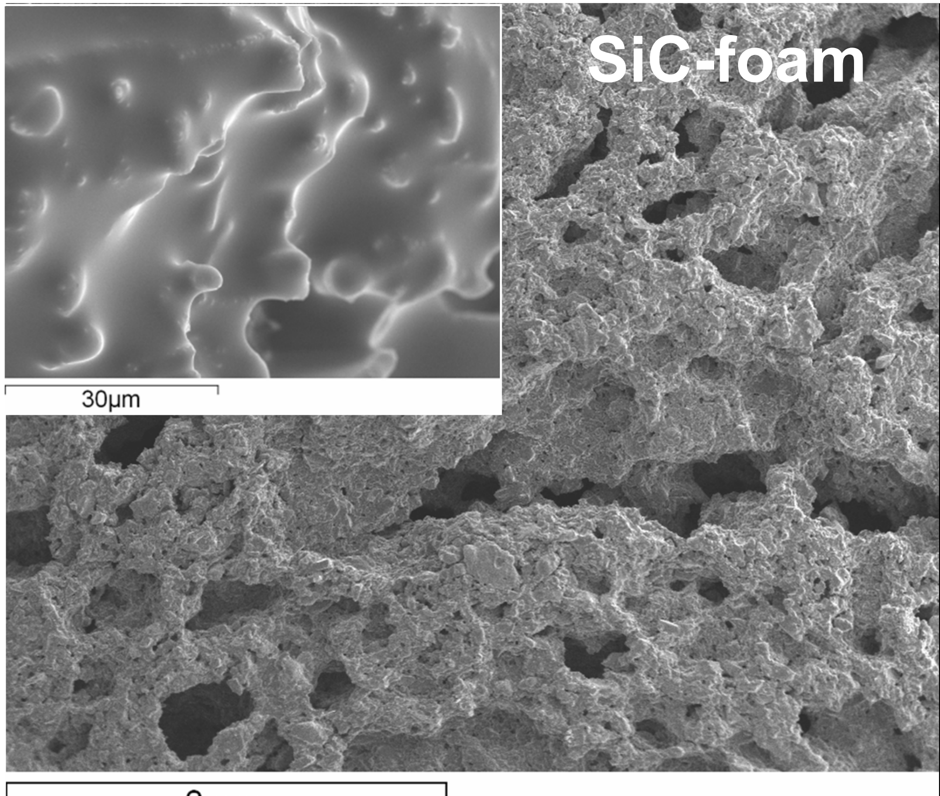
Good adhesion: absence of exfoliation or detaching upon cutting and polishing.

Scratch test performed on coating (Ra<10µm) applied on a Si_3N_4-TiN substrate using a Rockwell C-like conic tip (200 µm radius, 100 N/min loading rate, 10 mm/min).

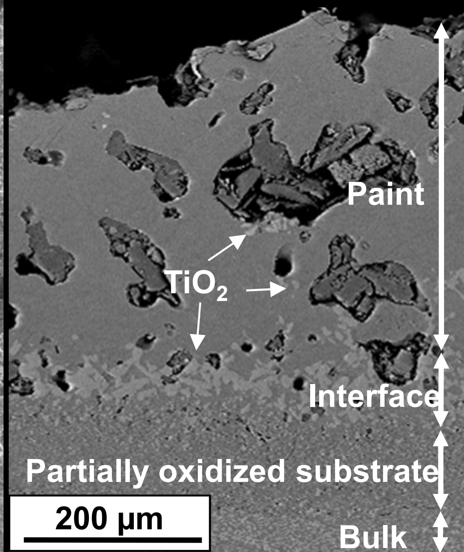
Delamination starts at 30 N

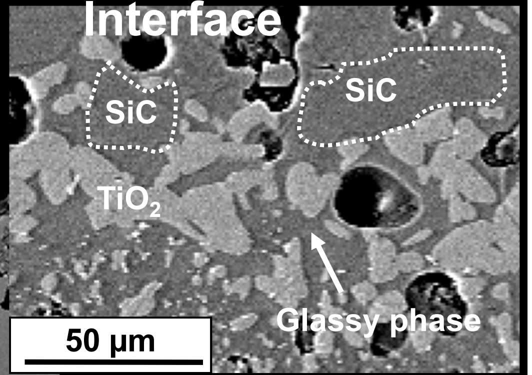


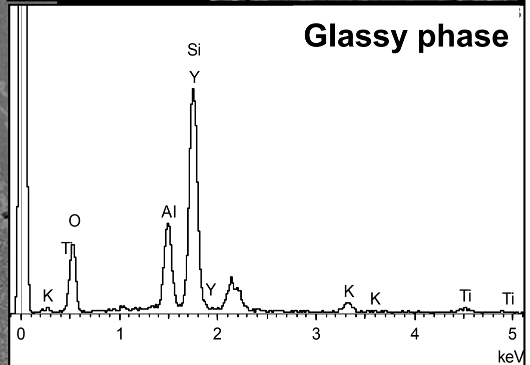
Long term oxidation: 100 h at 1200°C



- Weight gain +7%
- No change in macro-porosity and no shrinkage
- Formation of protective glass layer (SiO_2+leucite): no intrinsic porosity

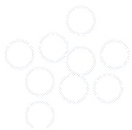
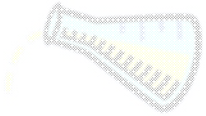
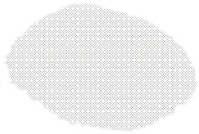




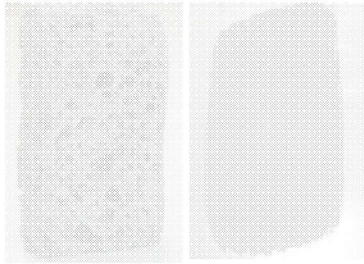


- Partially oxidation of the Si_3N_4-TiN
- Preventing of surface damage →
No visible delamination by scratch test: the glassy phase interdiffusion allows a tight adhesion with substrate

Examples Overview

 +  + 

metakaolin KOH/K_2SiO_3 SiC



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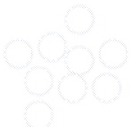
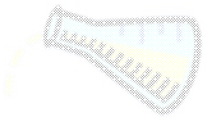
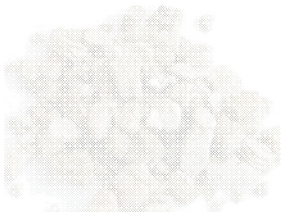
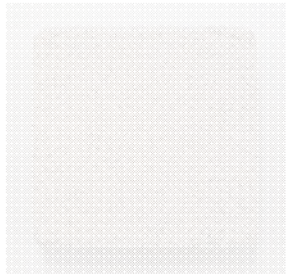
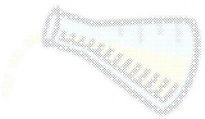
metakaolin KOH/K_2SiO_3 Ceramic wastes

 +  + 

metakaolin or alumina KOH/K_2SiO_3 vermiculite



 +  + 

alkali actived binder

biosoluble fiber

forming agent

Sandwich panels for thermal insulation and passive cooling

1. by recycling up to 80 wt% of non-hazardous industrial wastes such as porcelain stoneware scraps from waste tiles of the Emilia Romagna (Italy) ceramic districts;
2. by using geopolymer to avoid high T production process and to exploit the geopolymers water retention properties for cooling by water evaporation.

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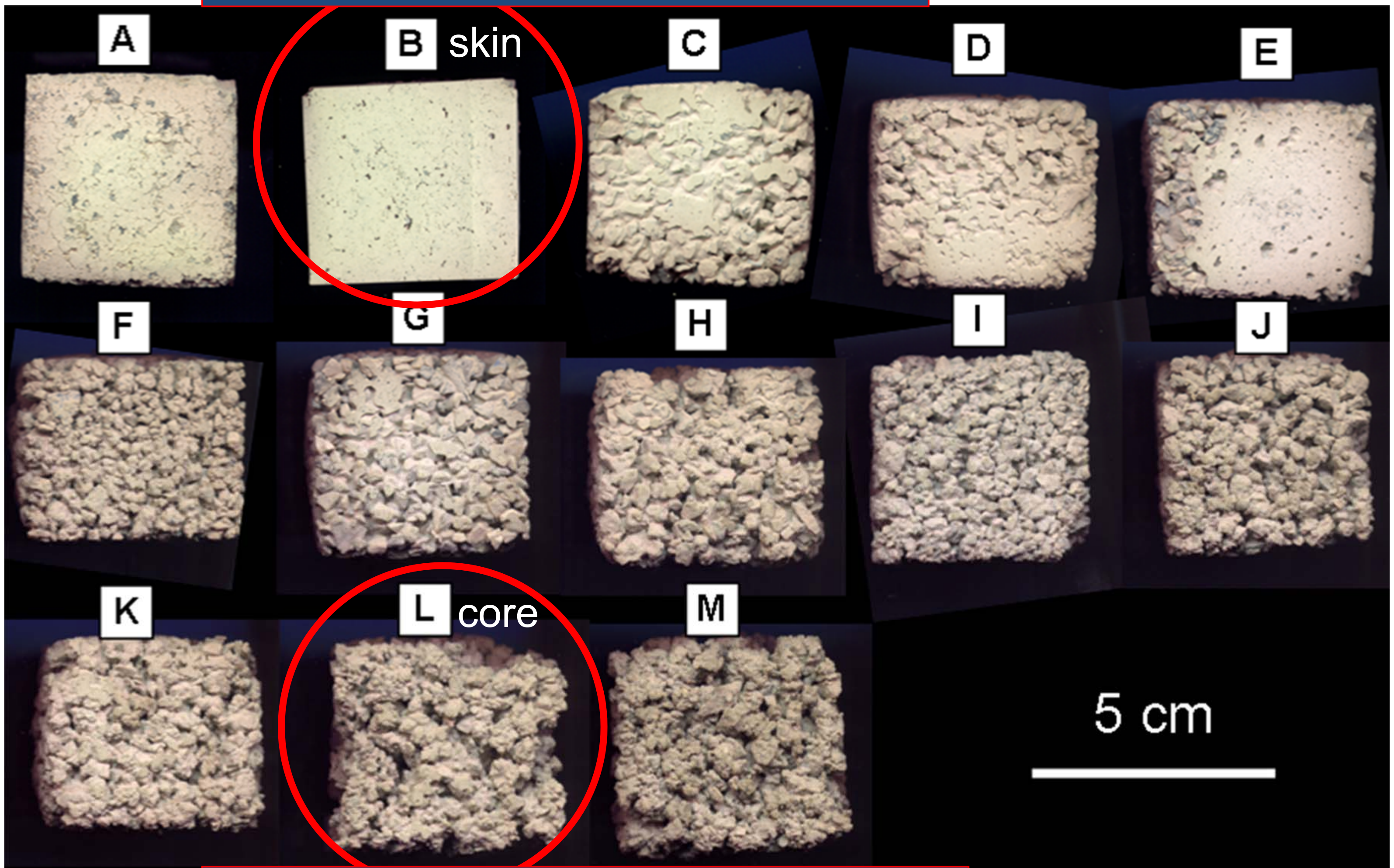
Porcelain stoneware scraps (partially reactive filler) are composed by mullite, quartz and feldspar in a glassy matrix

S1: fired	S2: fired + unfired
humidity: 2,99%;	humidity:0,08%;
> 5 mm = 2,52%;	>5 mm = 1,40%;
2 - 5 mm = 39,50%;	2 - 5 mm = 41,84%;
1 - 2 mm = 23,72%;	1 - 2 mm = 21,04%;
400 μm - 1 mm= 16,88%;	400 μm - 1 mm = 12,74%;
< 400 μm = 17,38%.	< 400 μm = 22,98%.

Core and skins production by a Trial & Error approach

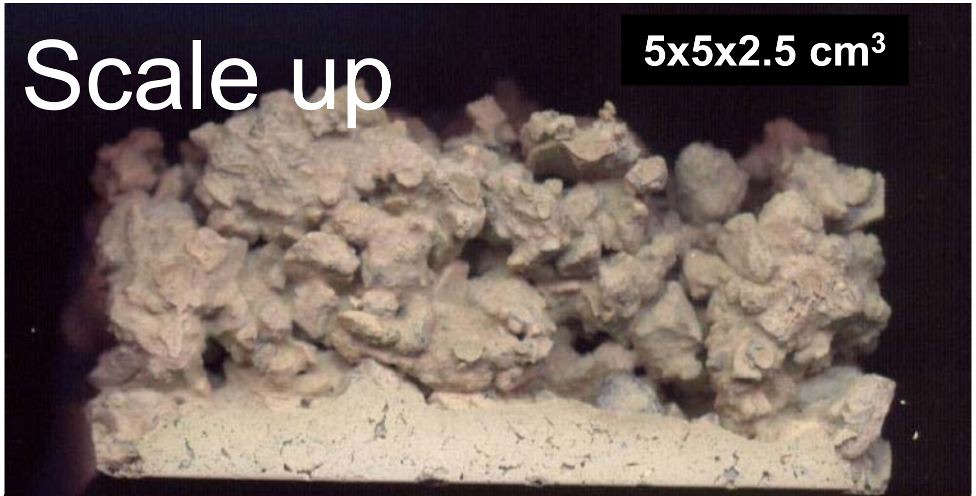
72 wt% scraps + water glass excess

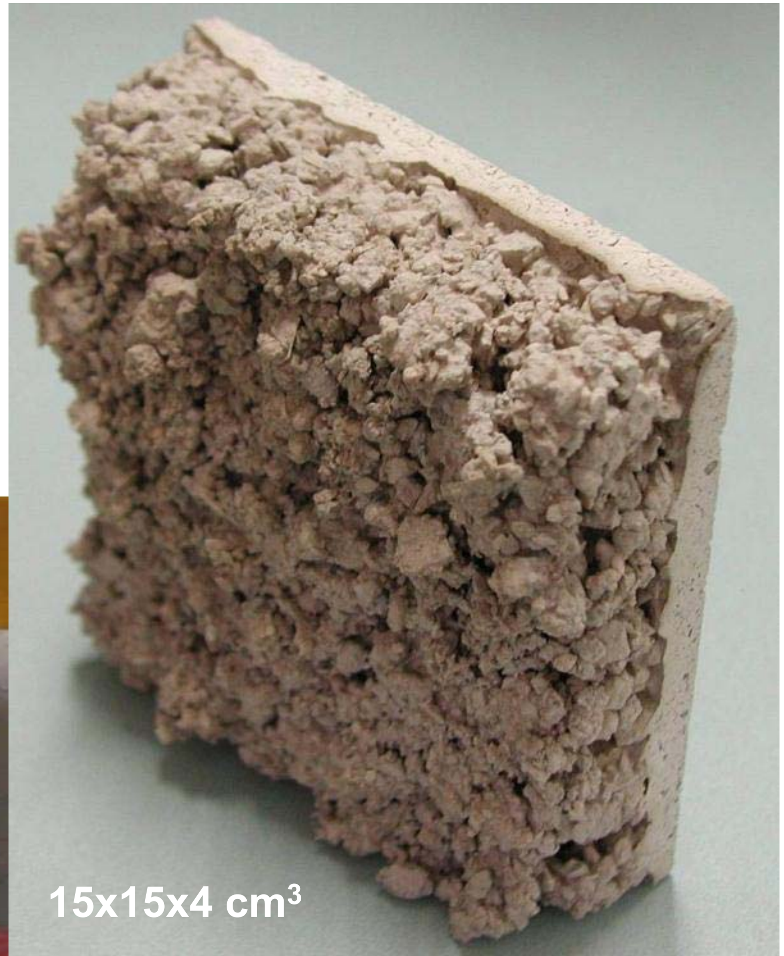
t 80°C in open mould



80 wt% scraps + stoichiometric binder

Scale up



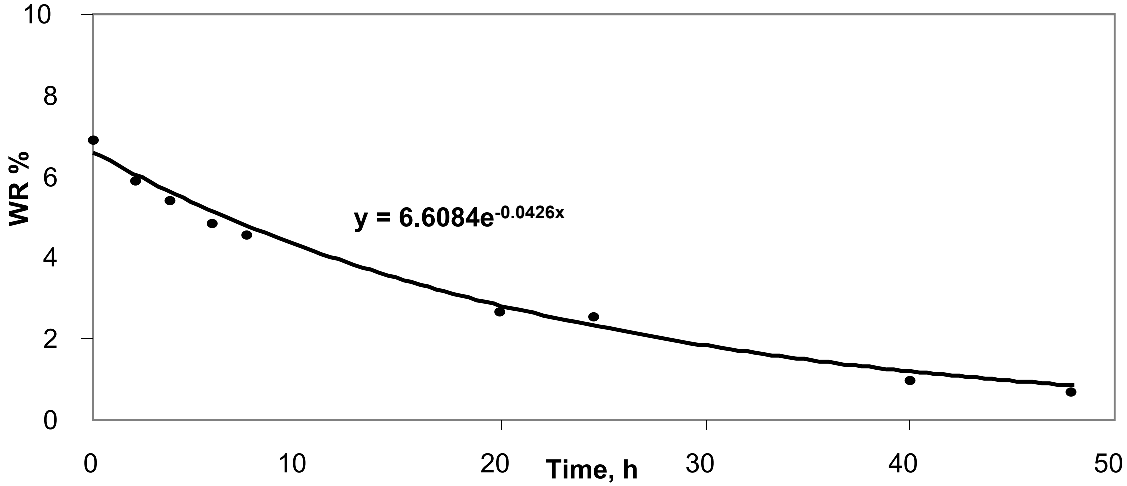


Density: ~1000 kg/m^3

Water capillary absorption and thermal insulation

C_{wis}= initial coefficient of water absorption by UNI EN 772-11 (2011)
WA= water absorption by full immersion in water for 1 minute
WS= weight increase after water saturation
C_{WR}= coefficient of water release **a** (in the first 20 h) and **b** (20-50 h)
λ = thermal conductivity by Guarded Hot Plate Apparatus (ASTM C177-97)

C_{wis}, kg/(m²·min)	WA, %	WS ,%	C_{WRa}, %/h	C_{WRb}, %/h	λ, W·m⁻¹·K⁻¹
2.4	6.9	9.2	0.2	0.07	0.7



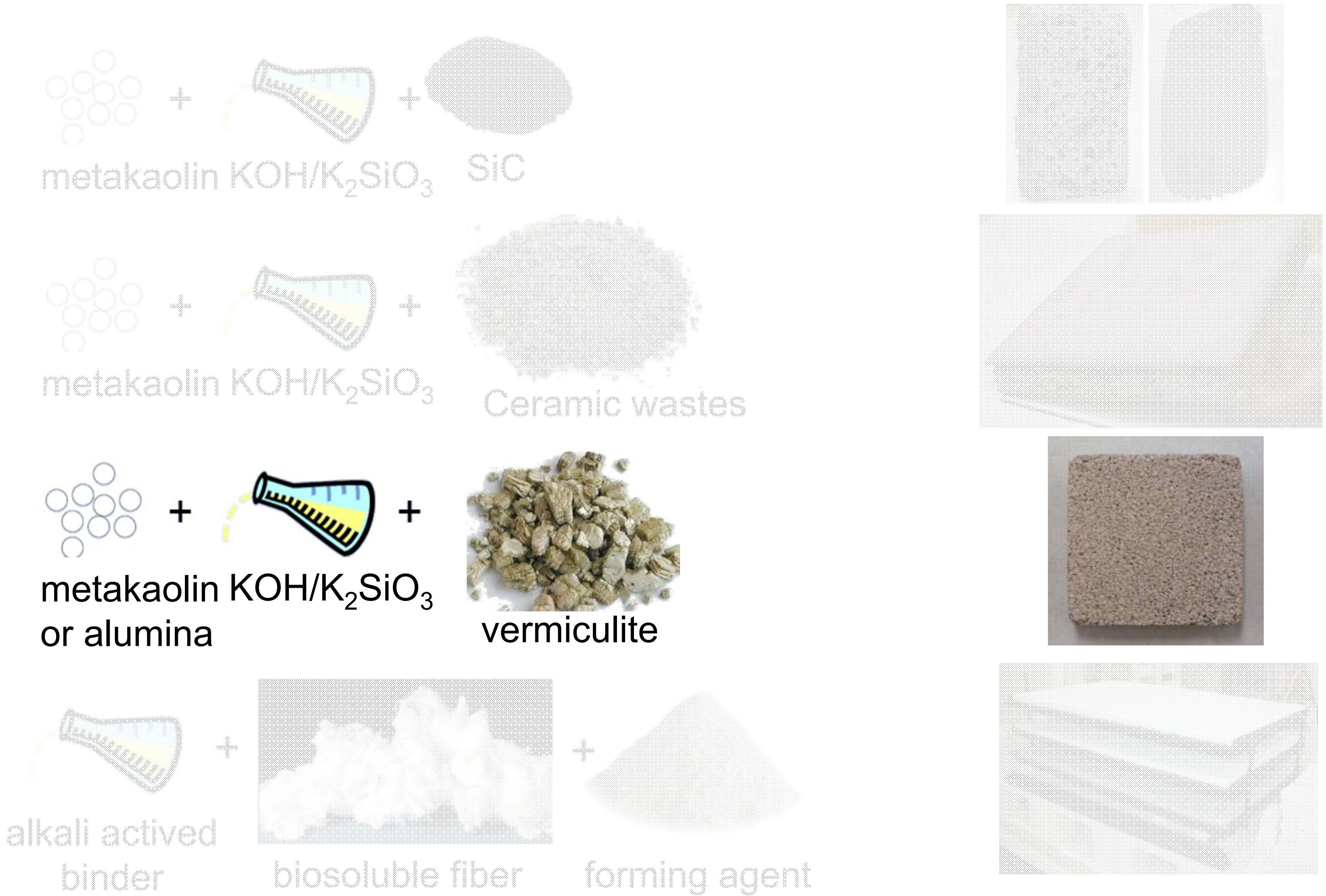
C_{wis} clay bricks ~1x10^{-2} kg/(m^2·min) (Raimondo *et al*, 2009)

WS geopolymers ≥ 60% (Okada *et al*, 2009)

λ scraps ~1.5 W·m^{-1}·K^{-1} (Garcia *et al*, 2011)
λ geopolymers 0.4-0.8 W·m^{-1}·K^{-1} (Duxon et al, 2006)

The low weight increase due to water absorption should not determine an excessive structural overload.

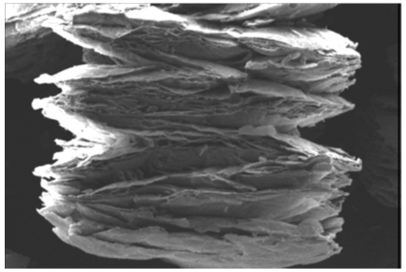
Examples Overview



Vermiculite based structural panels

Vermiculite

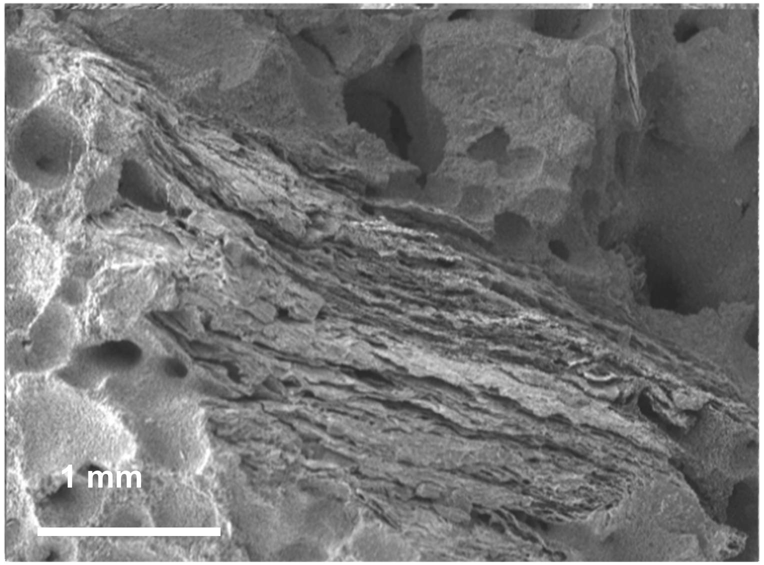
It is a natural mineral that expands under heating.
The bulk density is in the range of 64-160 kg/m³.

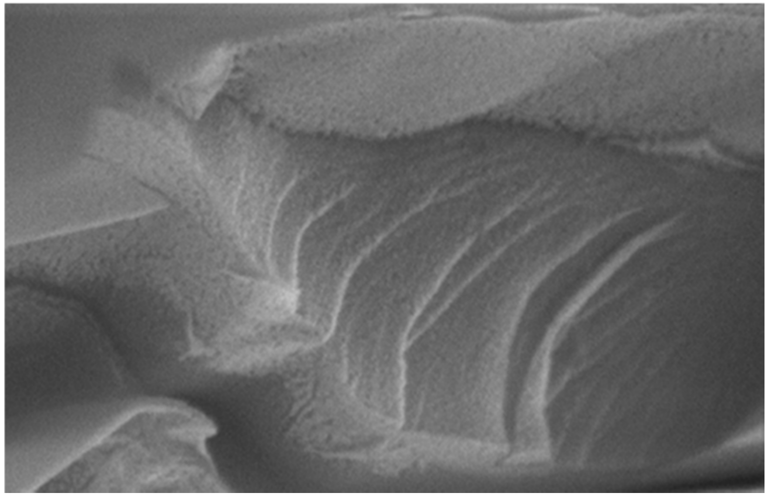


Commercial uses

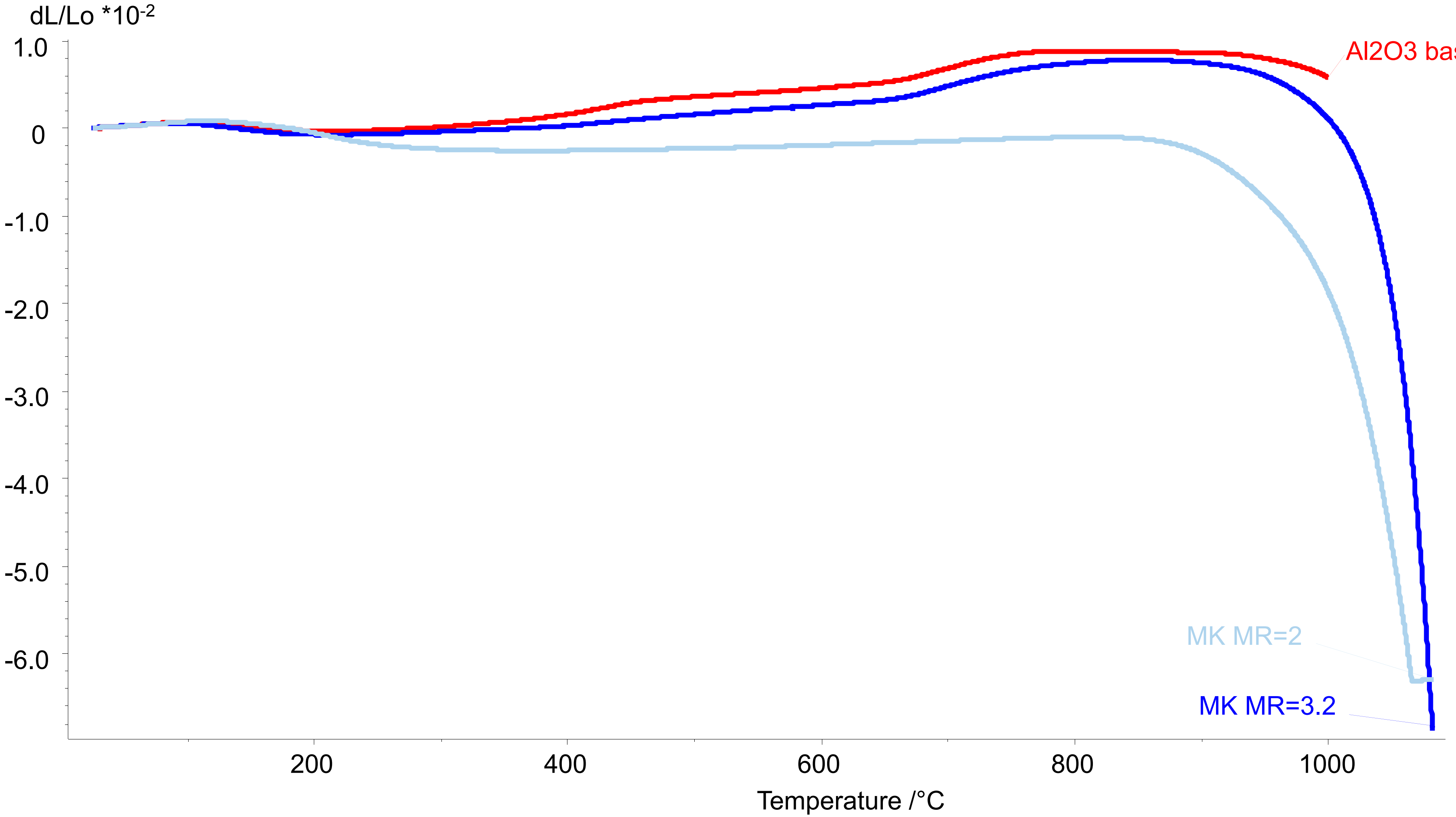
• molded shapes, bonded with sodium or potassium silicate for use in:
  - high-temperature insulation
  - refractory insulation
  - fireproofing of structural steel and pipes

• additive to fireproof wallboard
• etc…

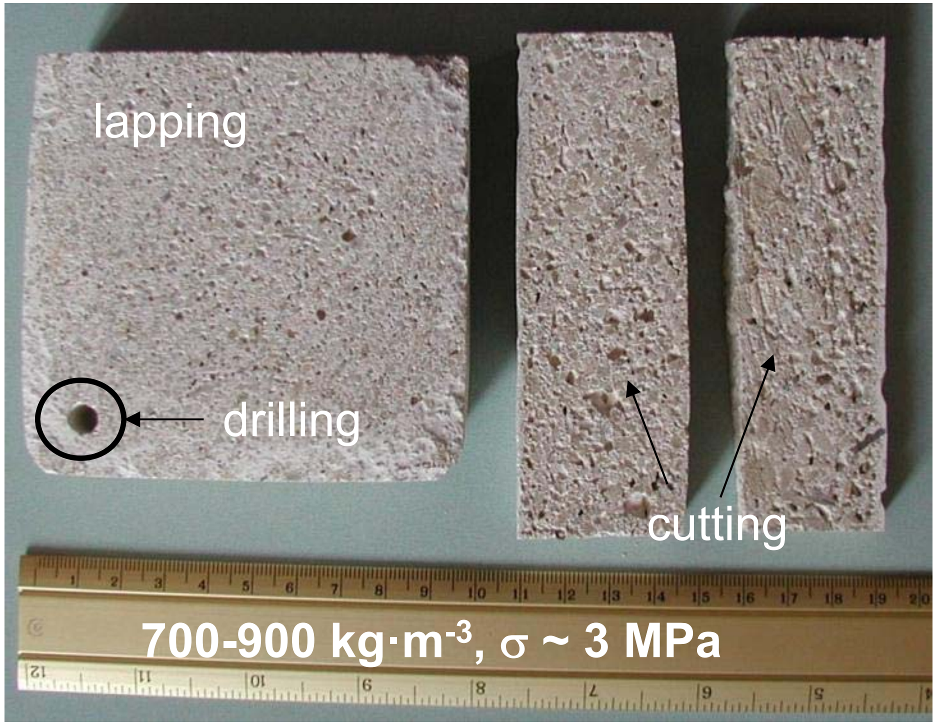




Dilatometric plots



Vermiculite based structural panels



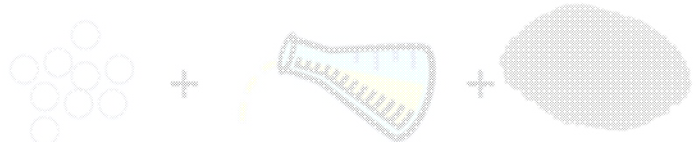
Funded by MATEC (MISE project)

New materials and new technologies for an internal combustion cogenerator prototype

- near net shaping by moulding
- easy machining
- higher or similar strength in respect with:

-cork (0.2-1.5 MPa)
-plaster board (5 MPa)
-cellular concrete (<1 MPa)

Examples Overview



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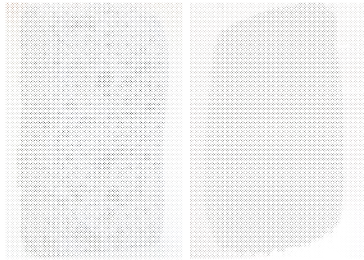

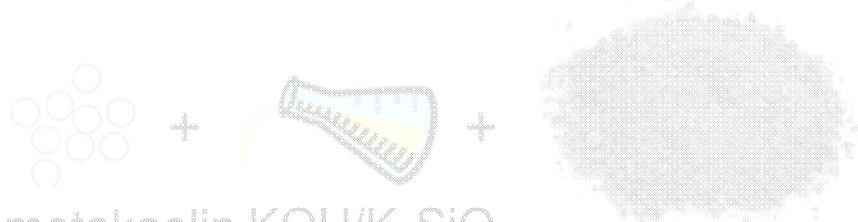

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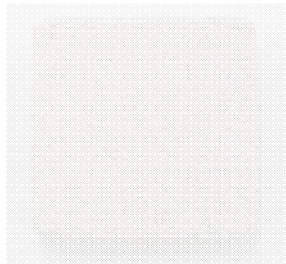

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alkali actived binder — biosoluble fiber — forming agent

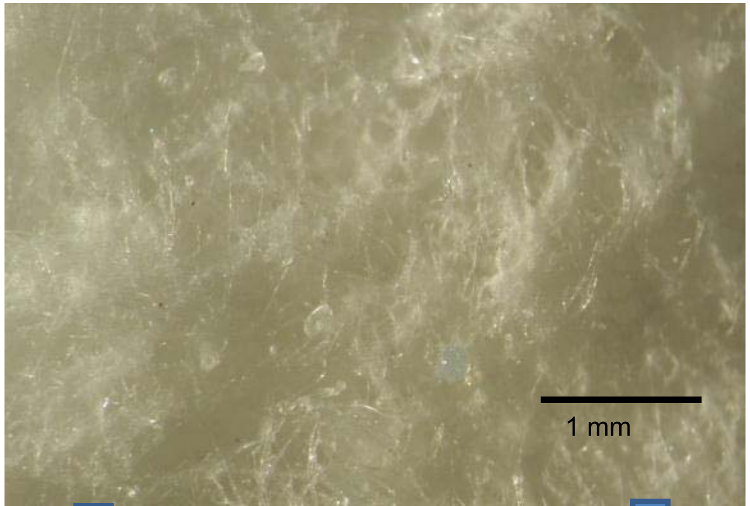
Light-weight panels for naval applications

Commercial bio-soluble fibers

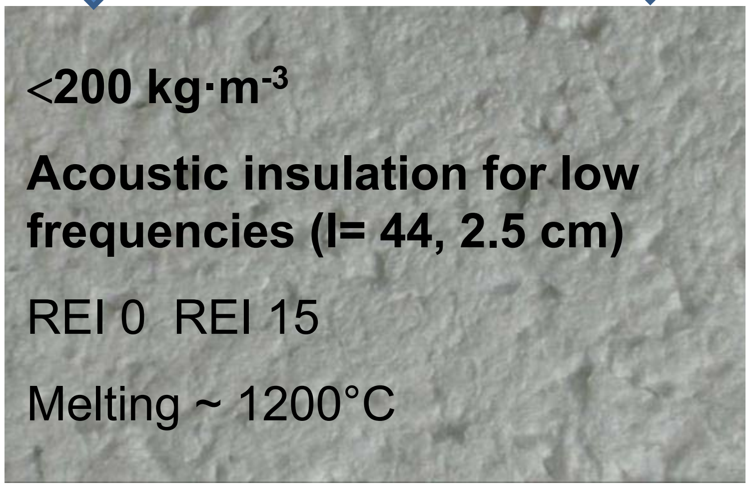
Fibers are based on a high purity calcia-magnesia-silica and have good thermal and physical properties up to 1200°C

Funded by RITMARE (flag project)

Development of materials and innovative solutions for partitioning panels with high noise reduction and fire resistance



Multi step process



<200 kg·m^{-3}

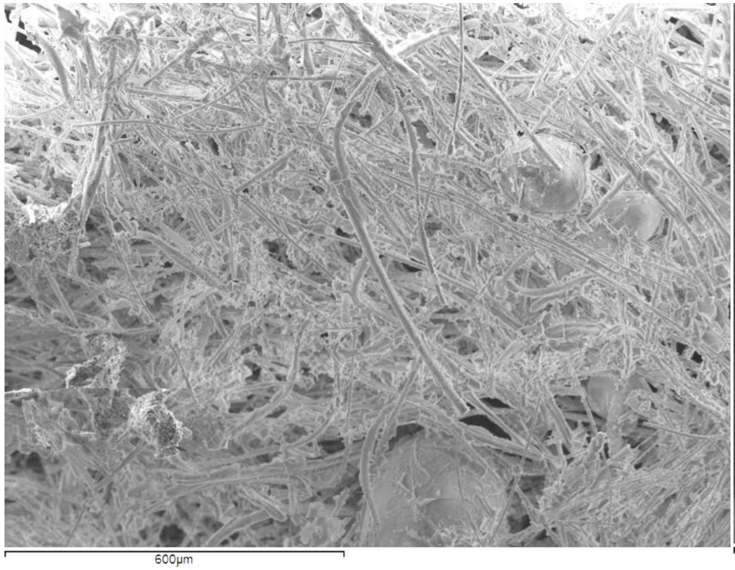
Acoustic insulation for low frequencies (l= 44, 2.5 cm)

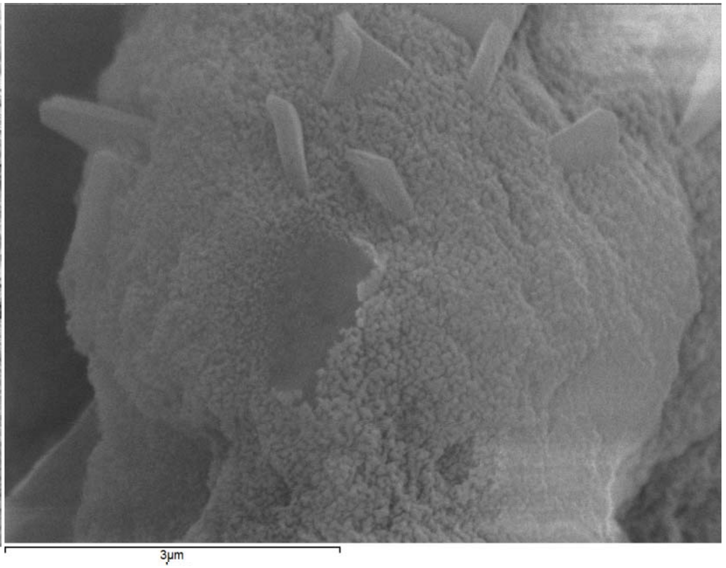
REI 0 REI 15

Melting ~ 1200°C

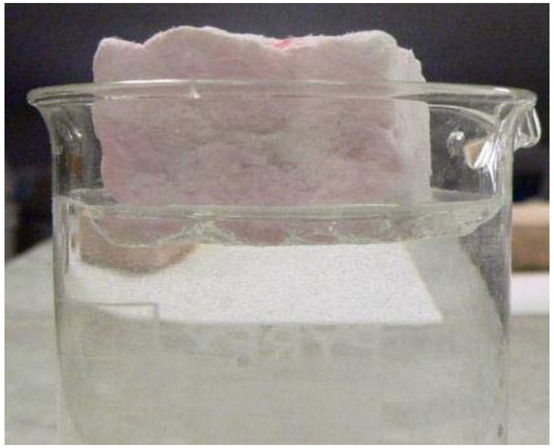
Scale up: 1 m^2, thickness 5 cm

Microstructure: macro-micro-meso-nano porosity





Imbibition with waterproofing



Conclusions

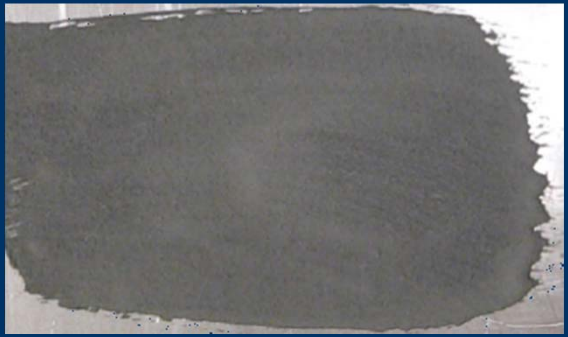
By using an alkali activated binder, it is possible to consolidate without using high T processes ceramic-like composite materials for different applications

Lightweight HT SiC device

Medri and Ruffini (2012)

HT SiC paints

Medri et al. (2010)



Thermal and acoustic insulation for buiding, industrial facilities and naval applications

Waste recycling in building materials Medri and Landi (2012)

«Geopolymer» CNR-ISTEC Staff thanks for the kind attention

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