Evaluation of ceramic proppants as heat transfer and storage medium

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NextChem
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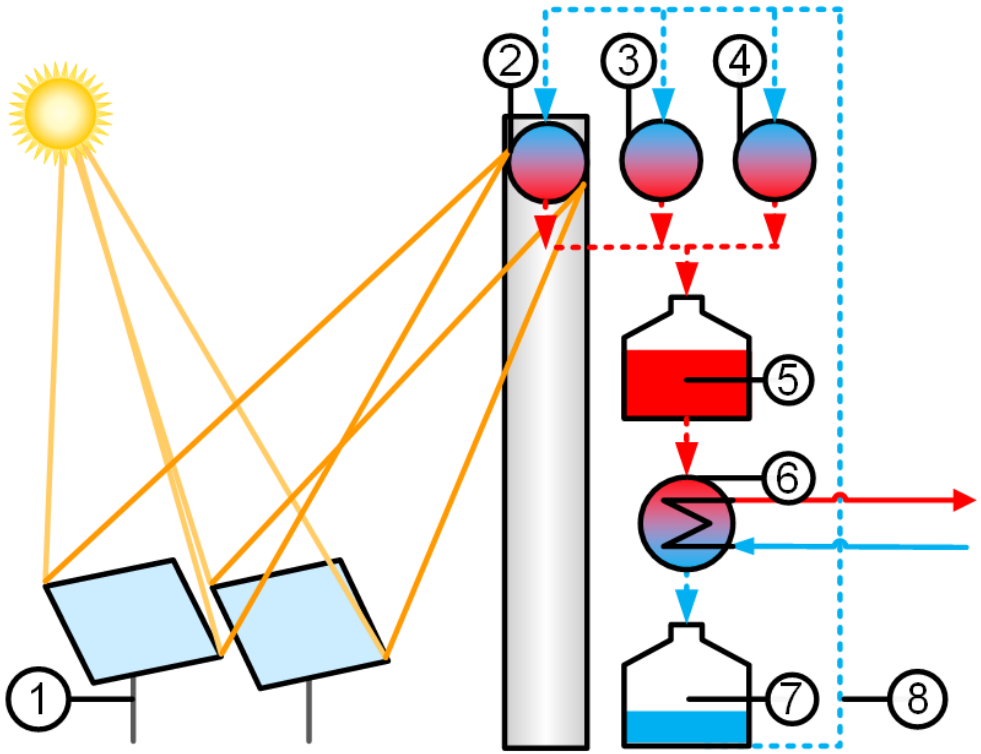
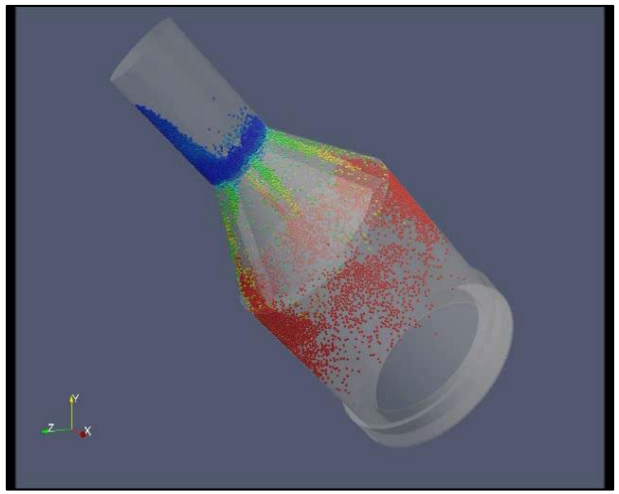
HIFLEX-Plant

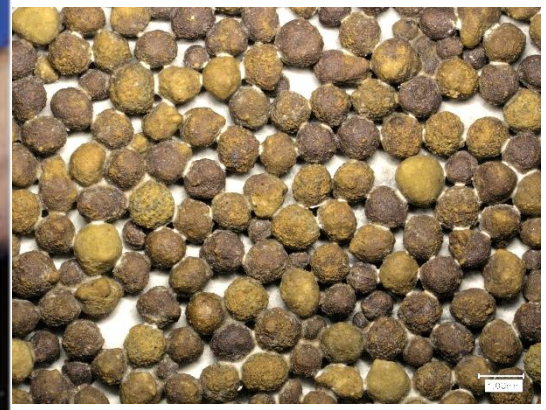


1. Heliostat Field
2. Direct Absorption Particle Receiver
3. Electric Particle Heater
4. Backup Particle Heater
5. Hot particle storage
6. Steam generator
7. Cold Particle storage
8. Particle Transport System

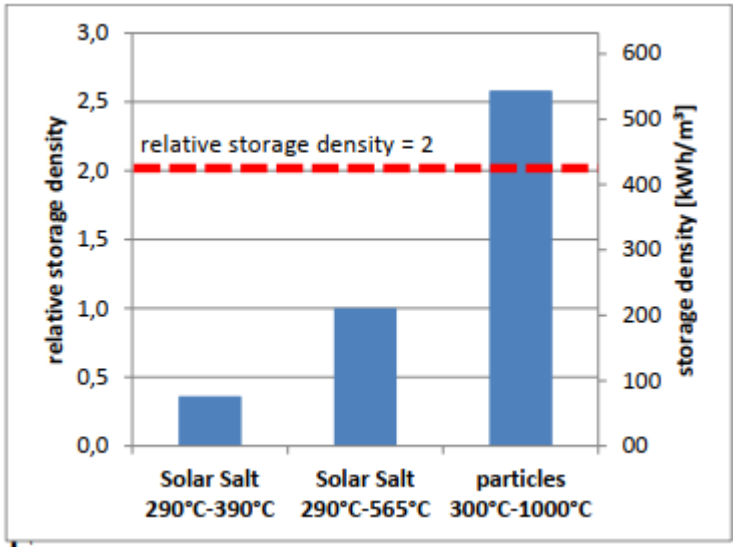


Details of the Plant Design: Detail Engineering of a High Storage Density Solar Power Plant for Flexible Energy Systems (Miriam Ebert, DLR)

Solid particles as heat transfer and storage medium in concentrating solar power plants



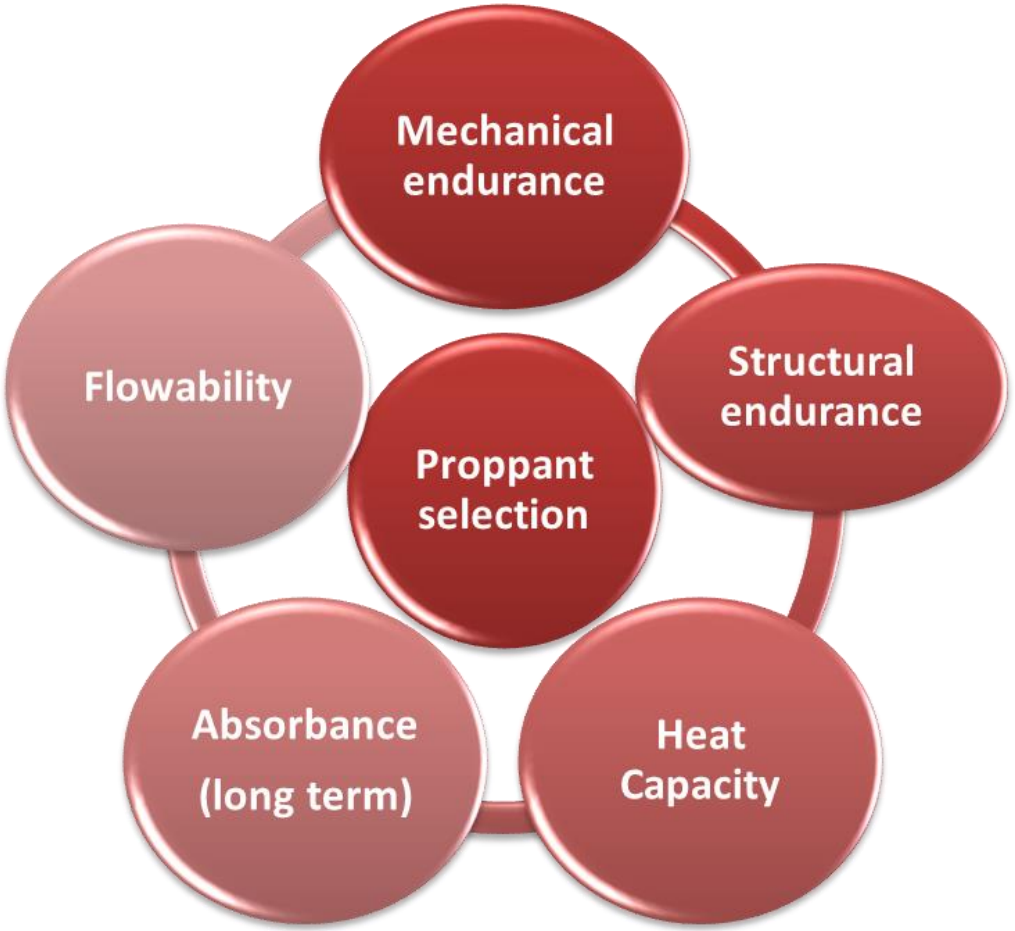
Bauxite based ´´proppants´´ produced for fracking industry



- Higher process temperature
- Wide temperature range 300-1000 ˚C; ~ 2 times higher storage density
- No risk of freezing like solar salts
- Low costs
- Good sphericity and thermal shock resistance

Objective of the study

- Investigation of the solar energy applications related properties
- Correlating the material properties with application related properties
- Proposing the most promising proppants



Materials & Experimental procedure

Proppants (16/30 mesh size)

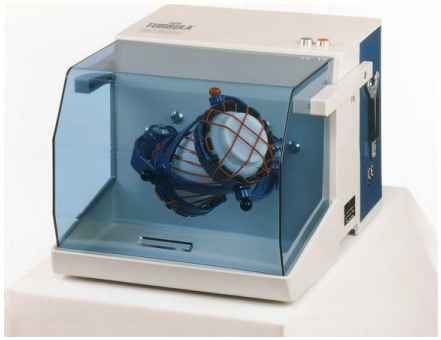
Seppe Technologies, China

Wanli Industry, China

Carboceramics, USA

Saint Gobain, France

Analysis methods



XRD - phase content *

SEM/EDX - microstructure/ chemistry*

High temperature compressive test - viscous flow temperature

Differential scanning calorimetry - heat capacity

Spectrophotometer (320-2500 nm) - absorptance *

Turbula mixer - abrasion resistance

Tilting box method - angle of repose

DIN 80 pipe (45° inclination) - mass flow rate

*** after thermal aging at 1000 ˚C for 1 week**

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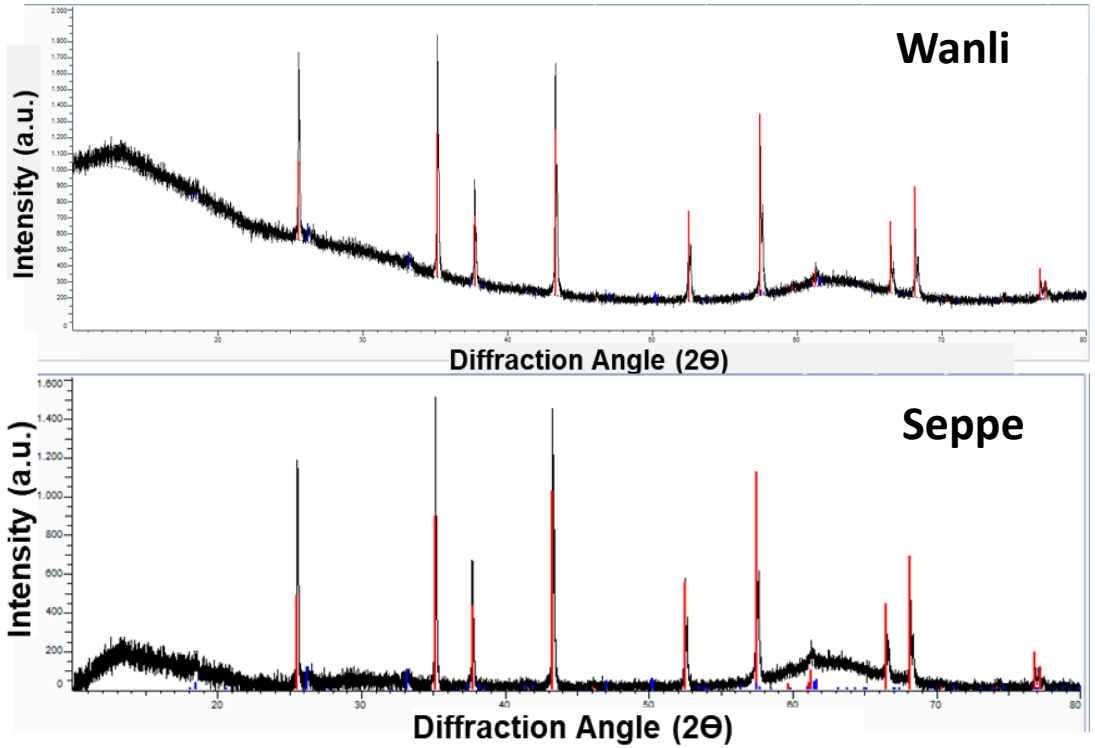
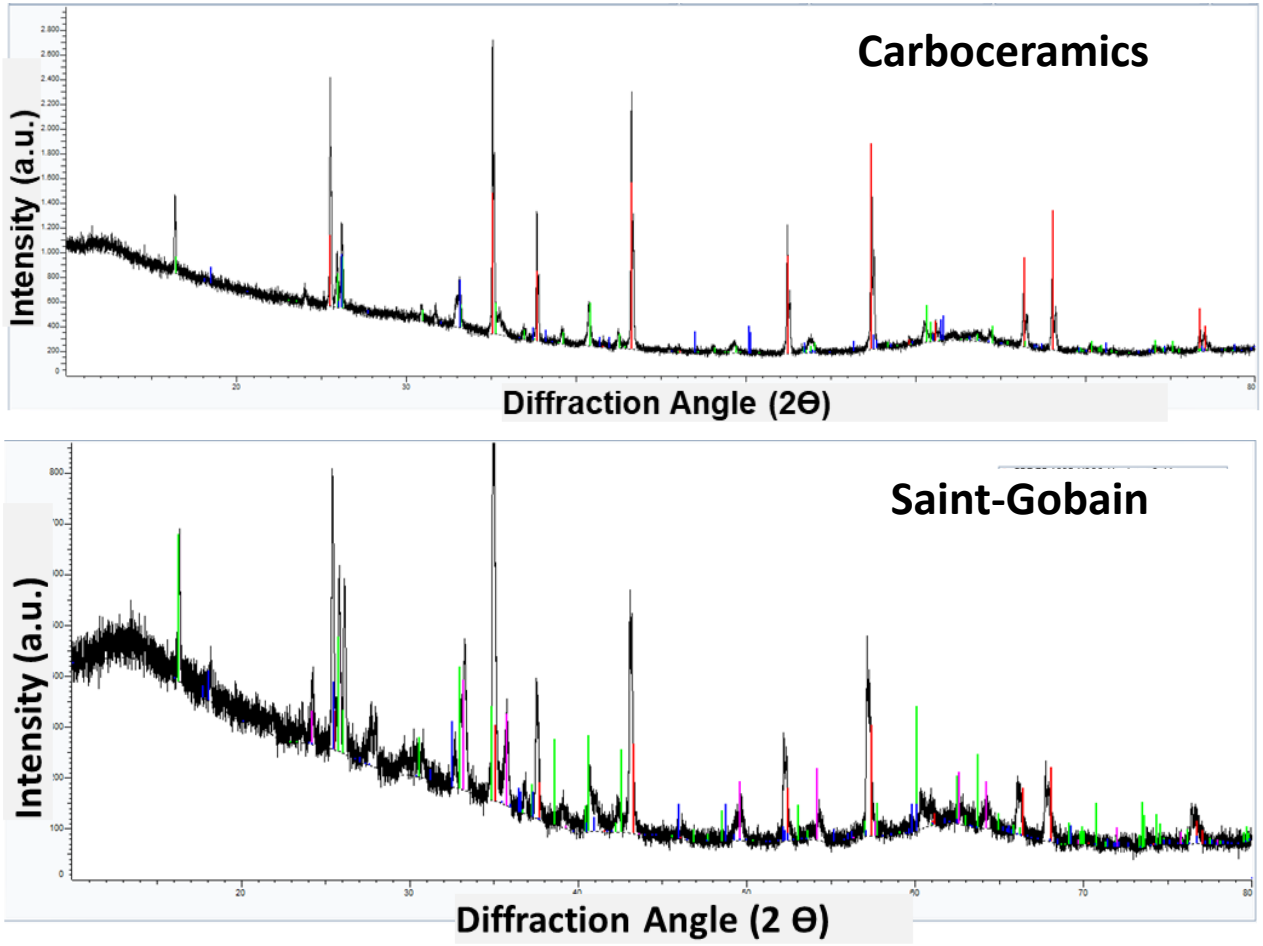
Understanding the phase components of the proppants: XRD Analysis



Corundum (Al_2O_3) dominated

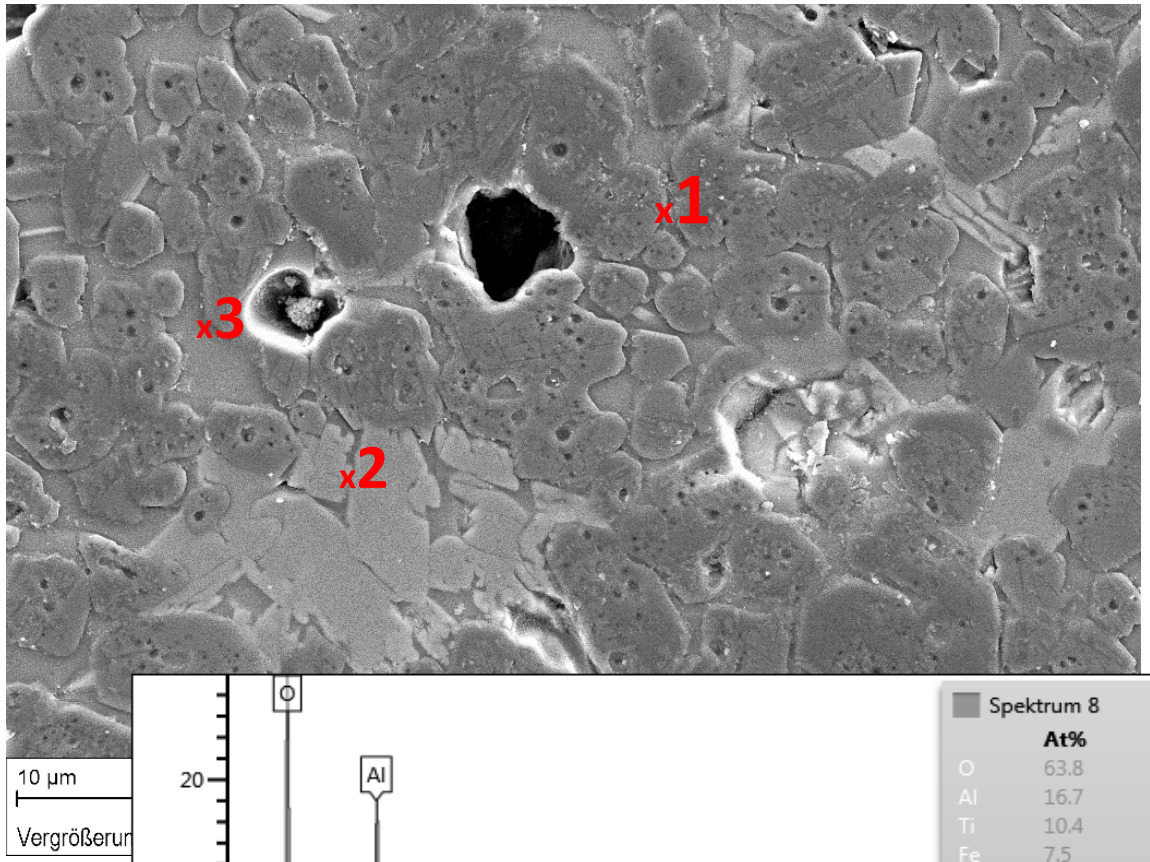


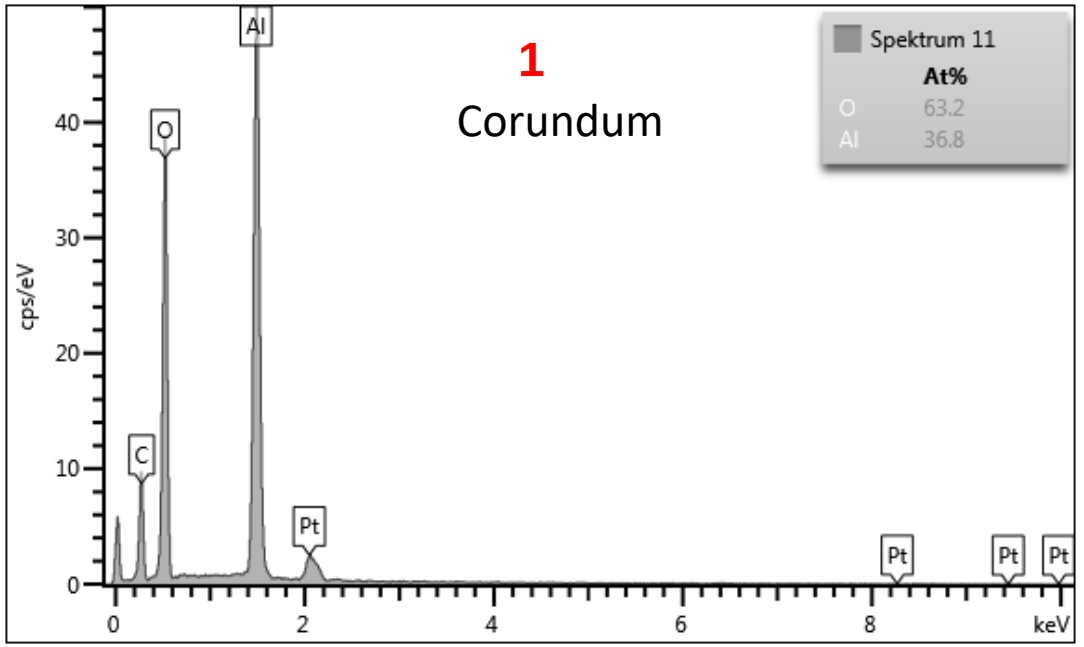
Corundum (Al_2O_3) **Mullite ($Al_6Si_2O_{13}$)**

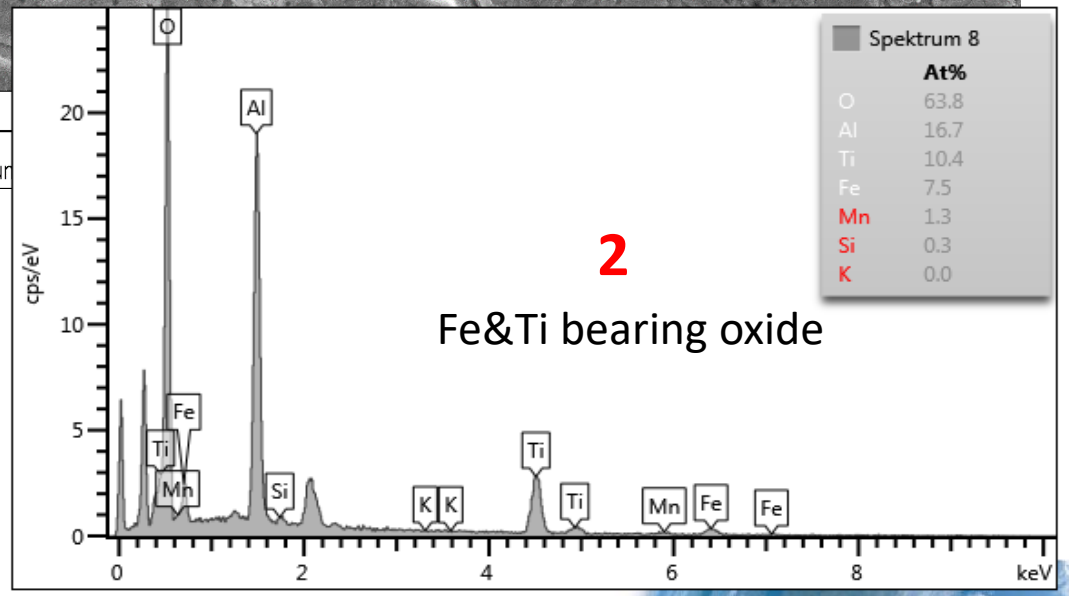
(Carboceramics) **Iron Aluminium Titanium Oxide ($FeAlTiO_5$)**

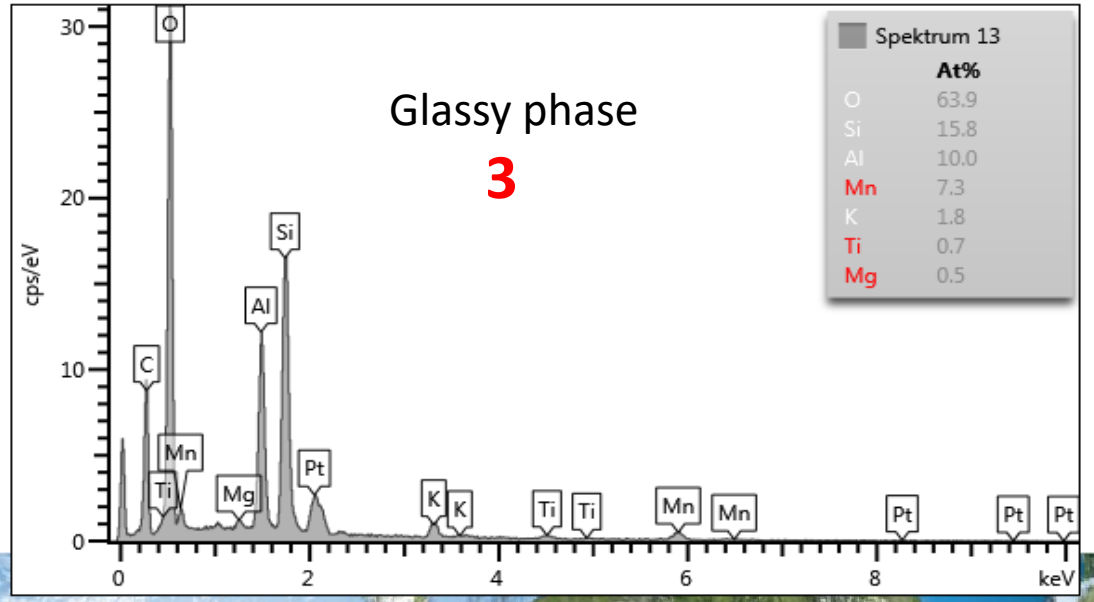
(Saint-Gobain) **Hematite (Fe_2O_3)** **Iron Titanium Oxide (Fe_2TiO_5)**

The microstructure and chemical analysis of the proppants: Wanli

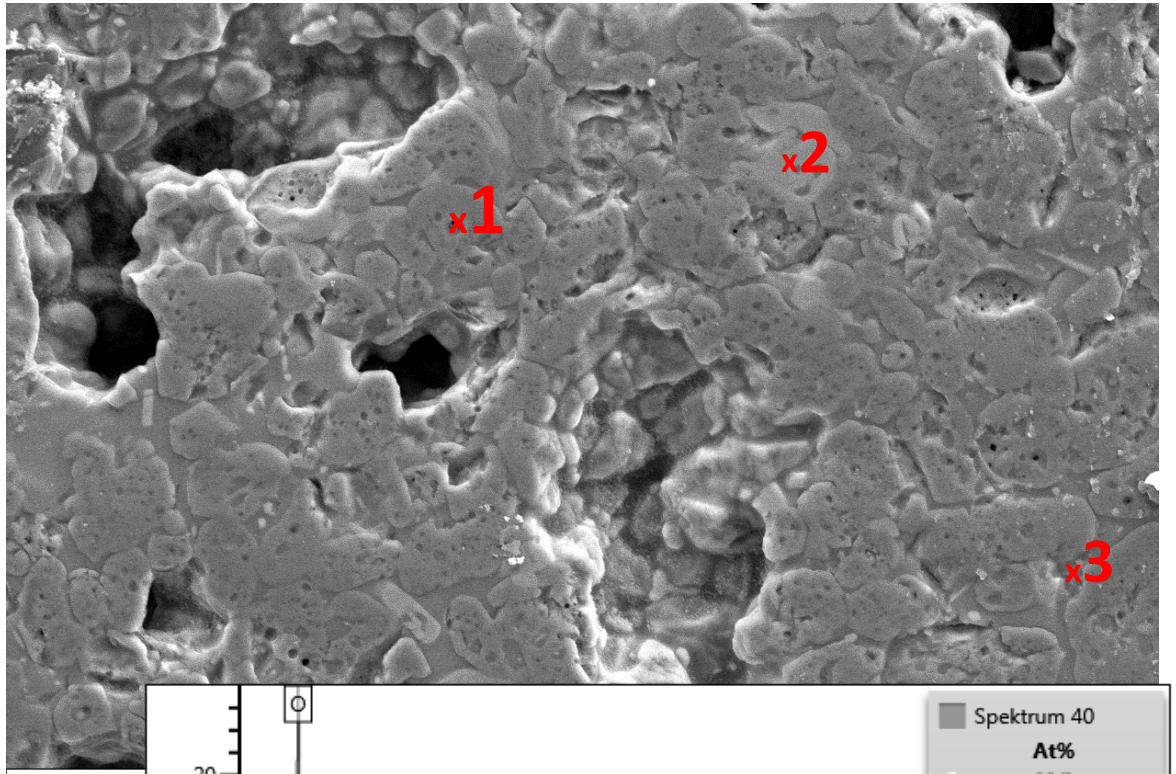


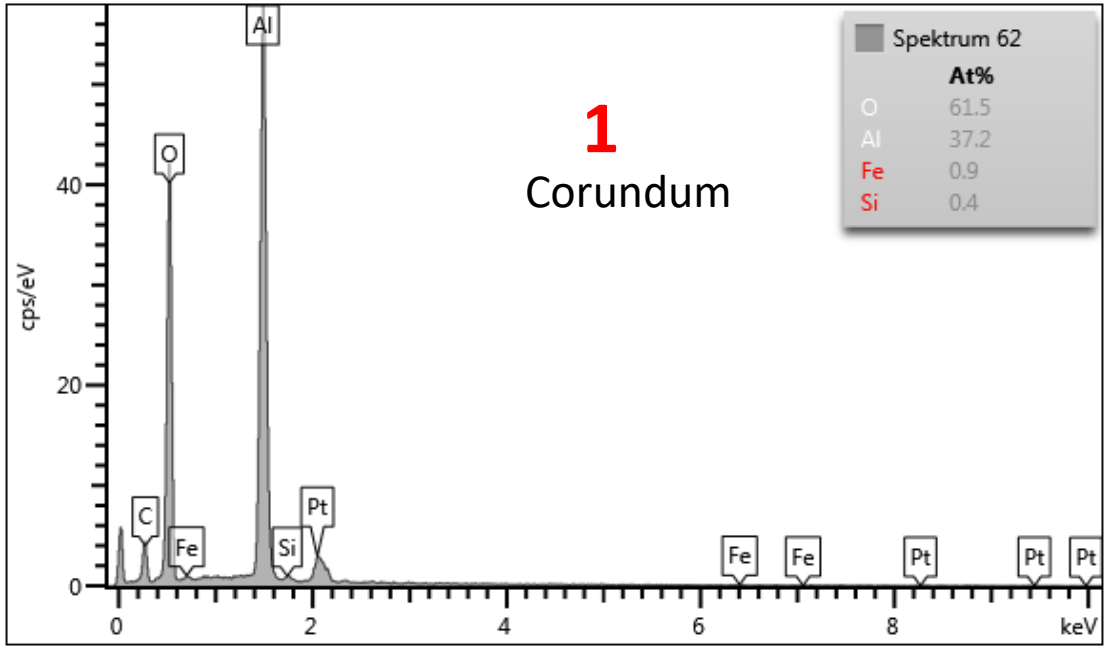


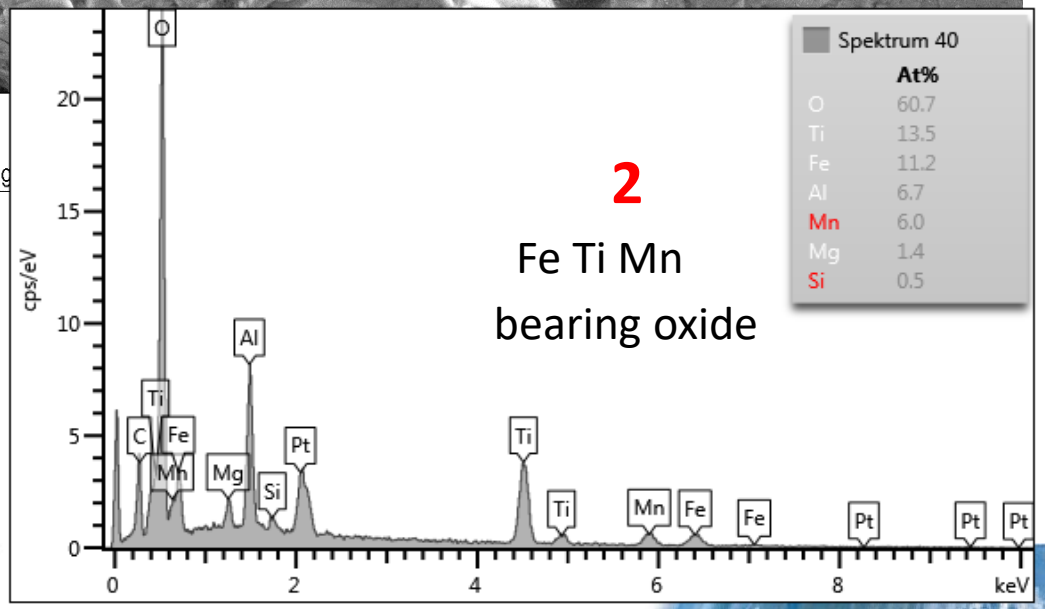


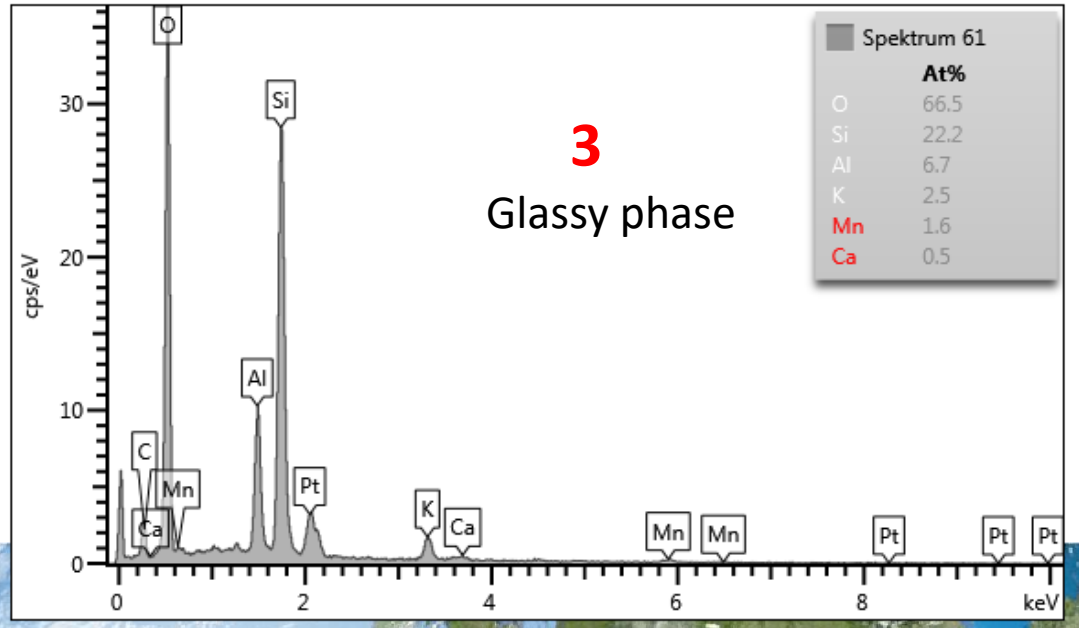


The microstructure and chemical analysis of the proppants: Seppe

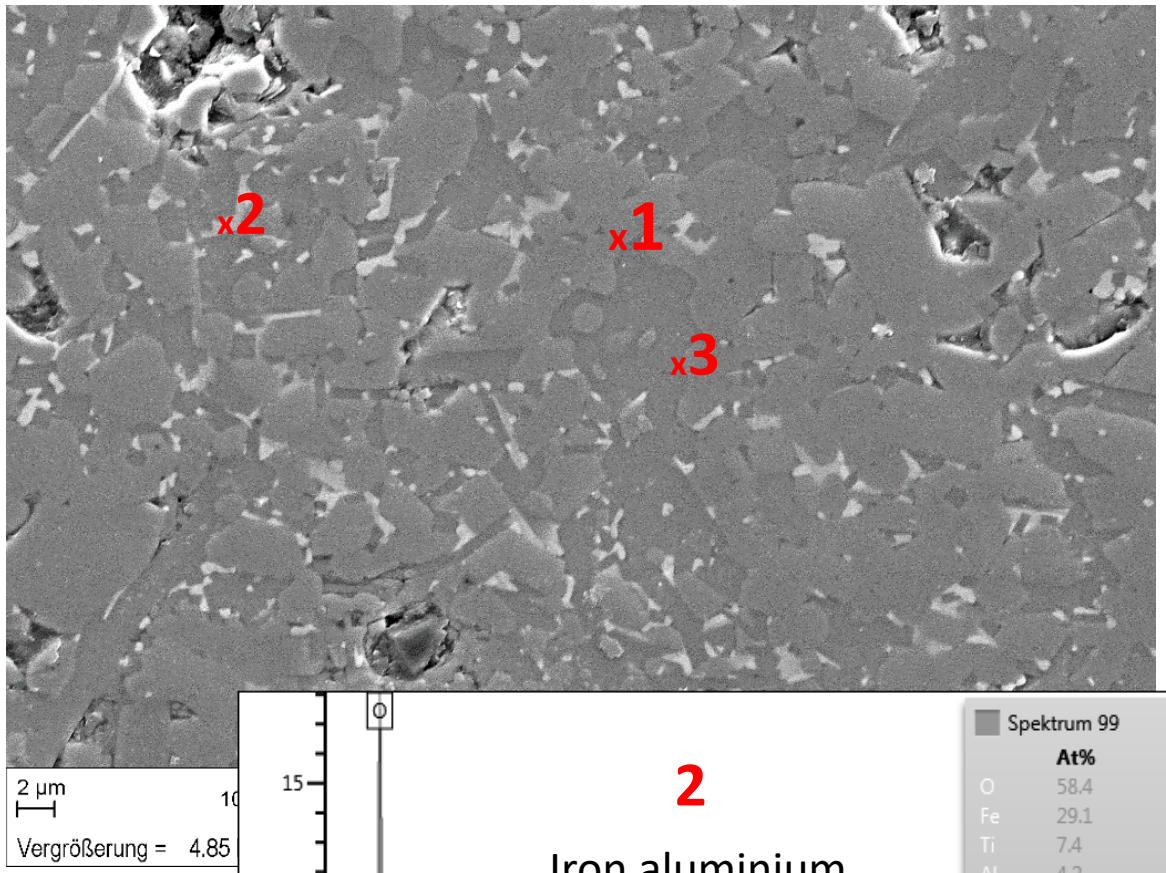


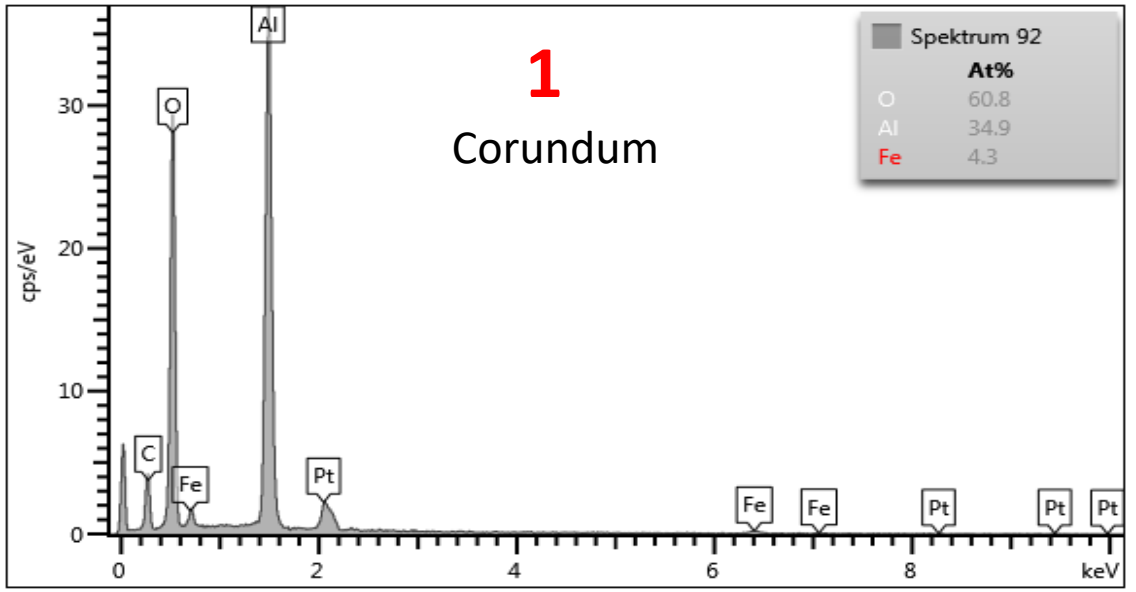


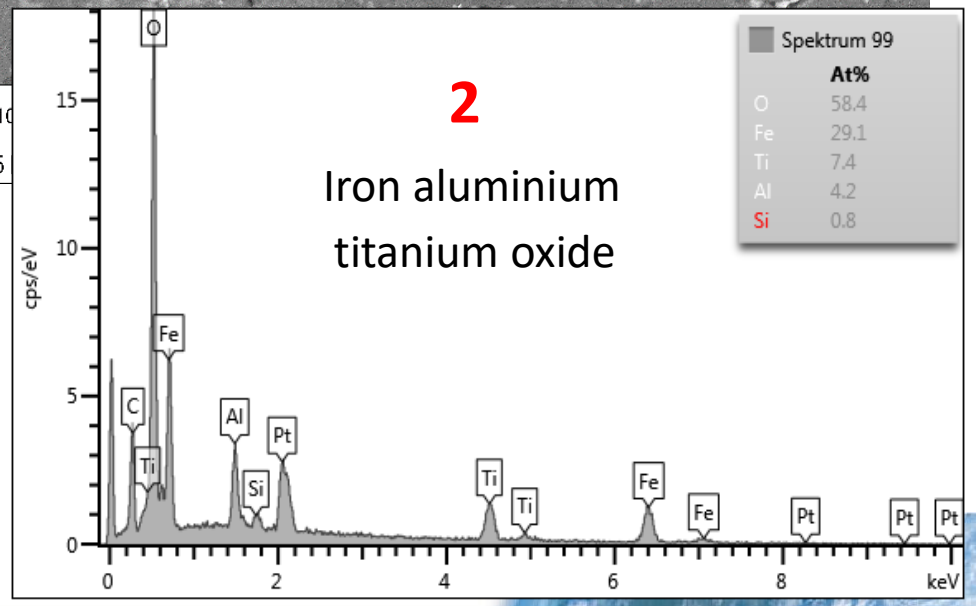


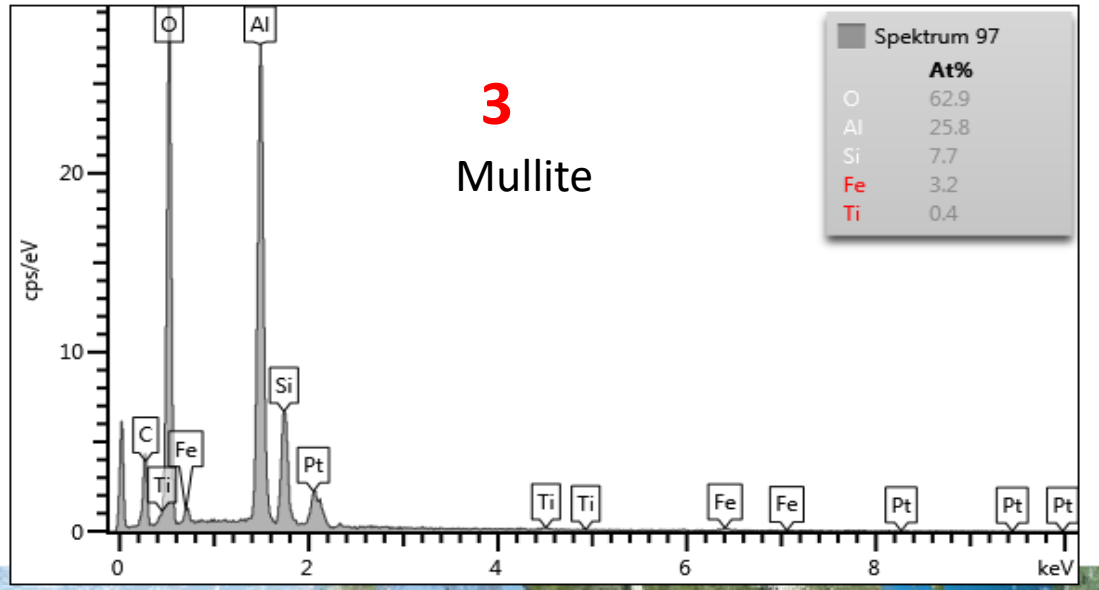


Understanding the phase components and microstructure of the proppants: Carboceramics

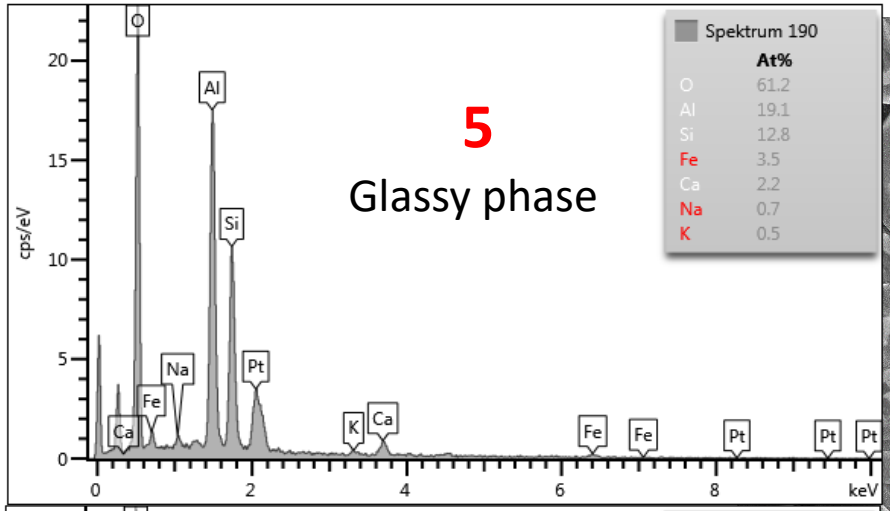






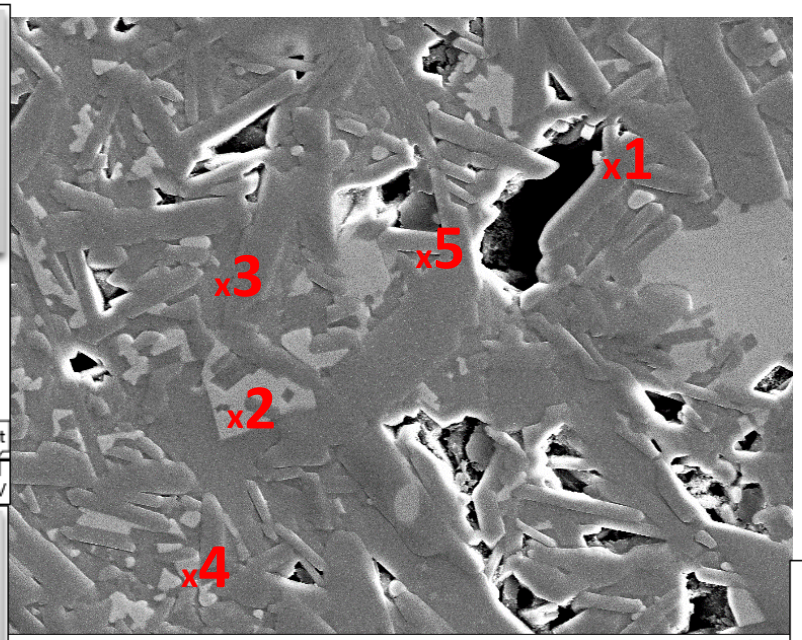


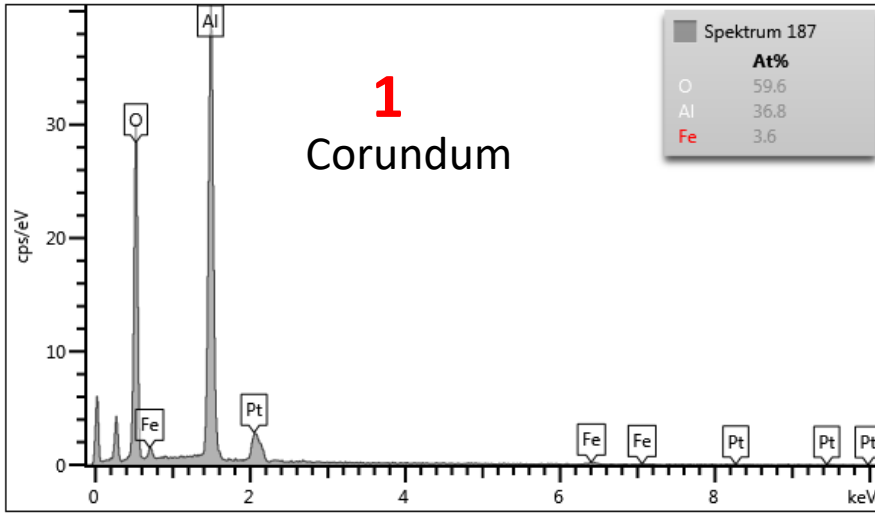
Understanding the phase components and microstructure of the proppants: Saint-Gobain



5

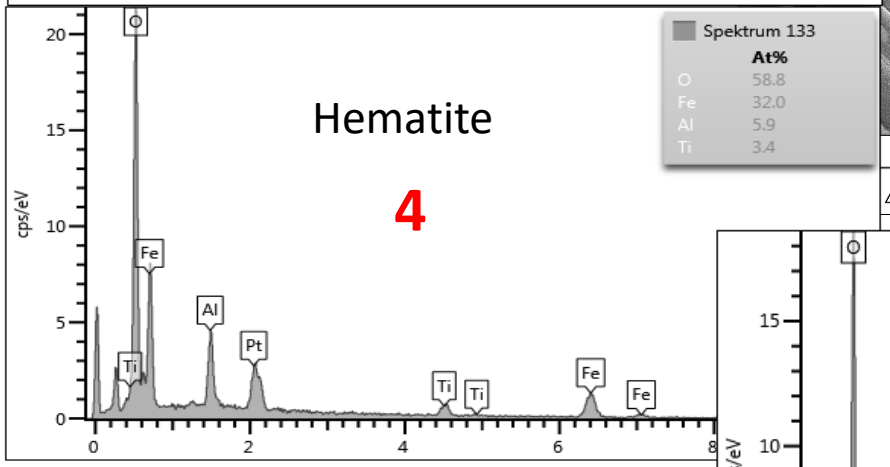
Glassy phase





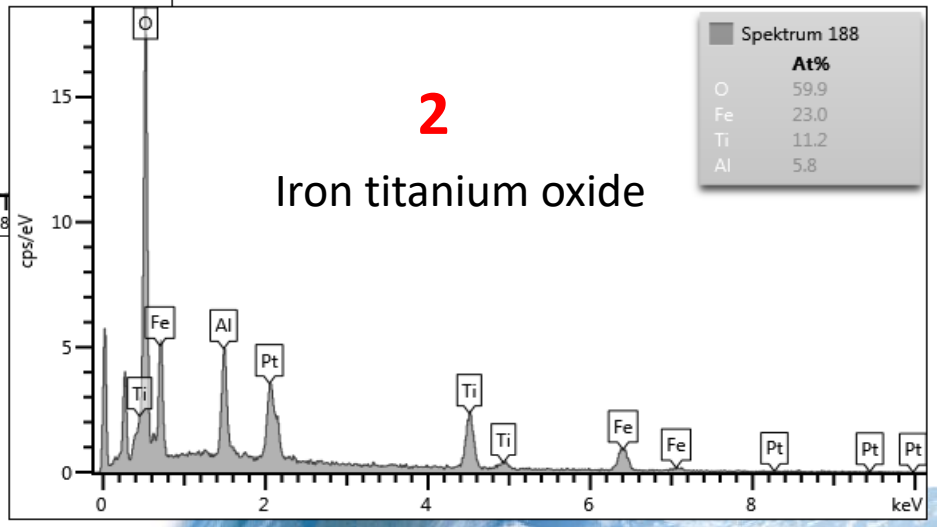
1

Corundum



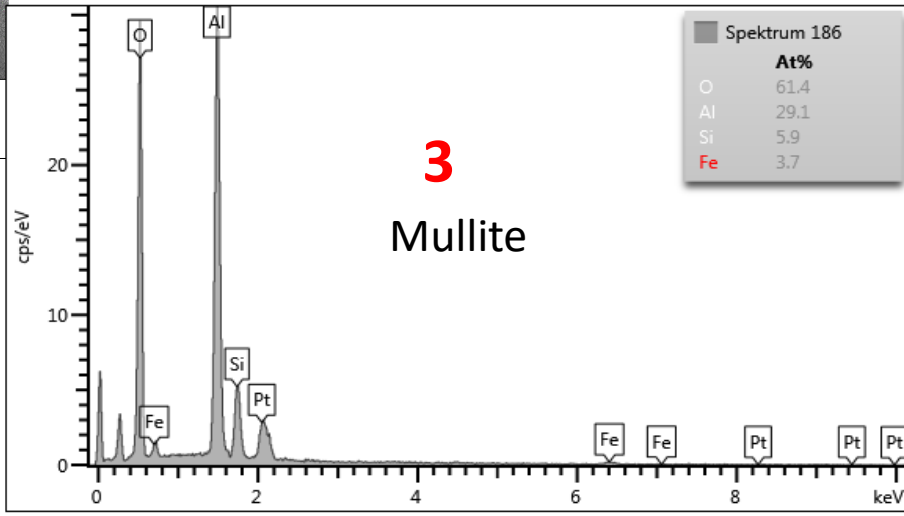
Hematite

4



2

Iron titanium oxide



3

Mullite

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Understanding the phase components and microstructure of the proppants: Comparison

➢ **Wanli & Seppe**

Corundum enriched microstructure

(high amount of glass phase, color giving elements are not well crystallized)

➢ **Carboceramics**

Corundum, mullite, iron aluminium titanium oxide

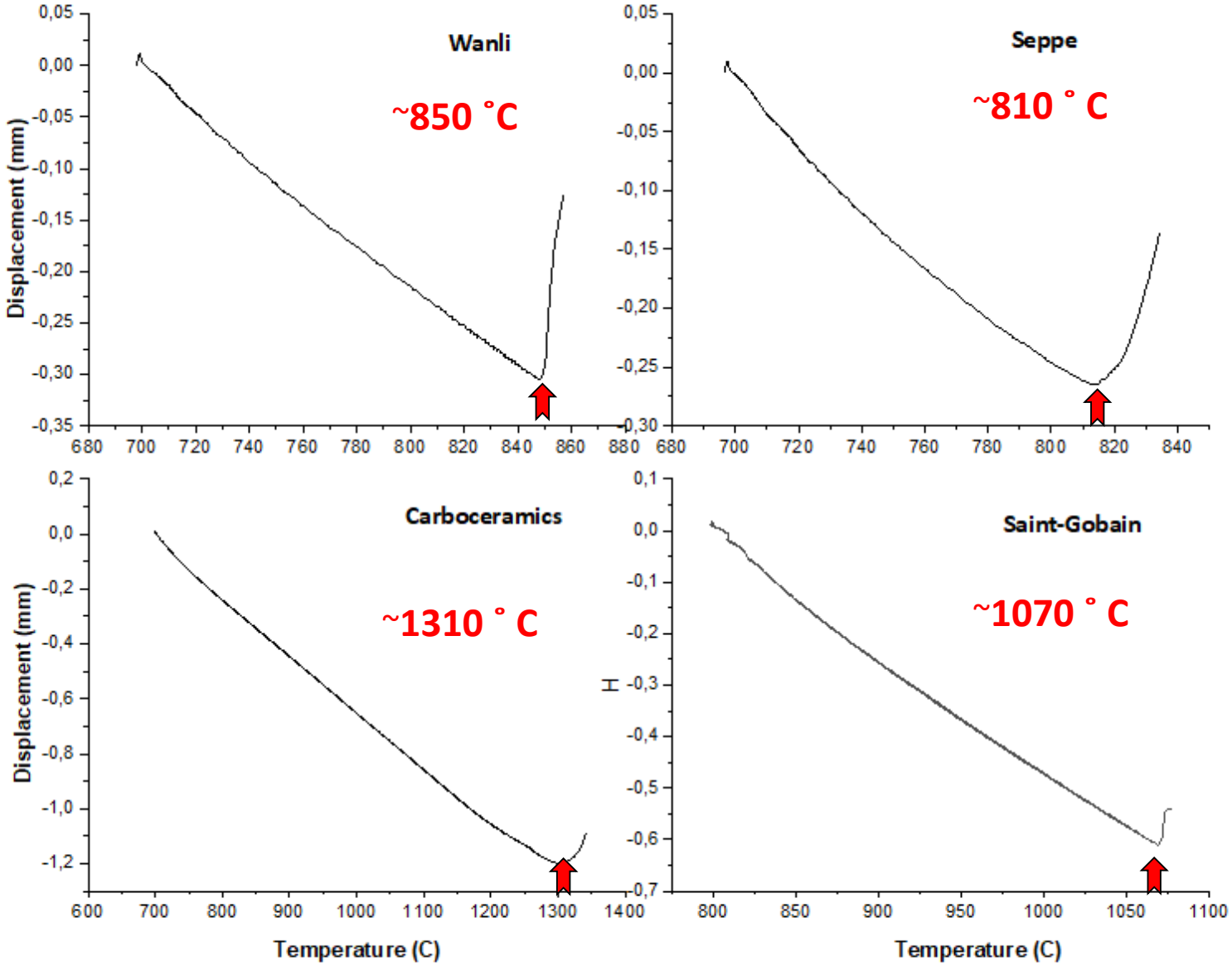
(well crystallized components and no glass phase)

➢ **Saint-Gobain**

Corundum, mullite, iron titanium oxide , hematite

(*well crystallized components and negligible glass phase)*

Assessment of the viscous flow temperature of the proppants

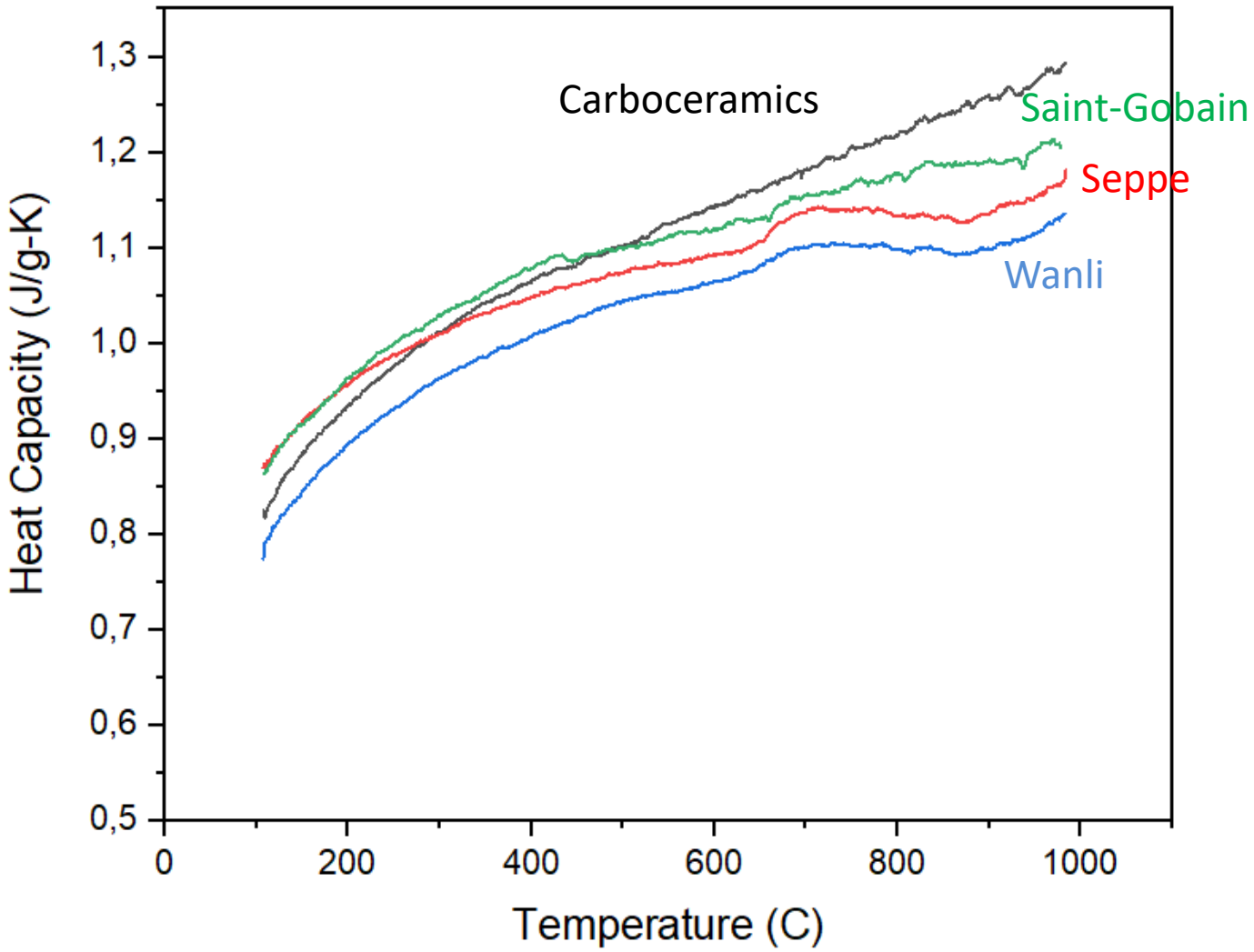


- **Seppe and Wanli;** low viscous flow temperature; due to the *high glass phase content*
- **Saint-Gobain;** promising (T> 1000 ˚C) *negligible glass phase*
- **Carboceramics;** superior high temperature endurance; microstructure *with no glass phase*

Well crystallized microstructure with minimized glassy components

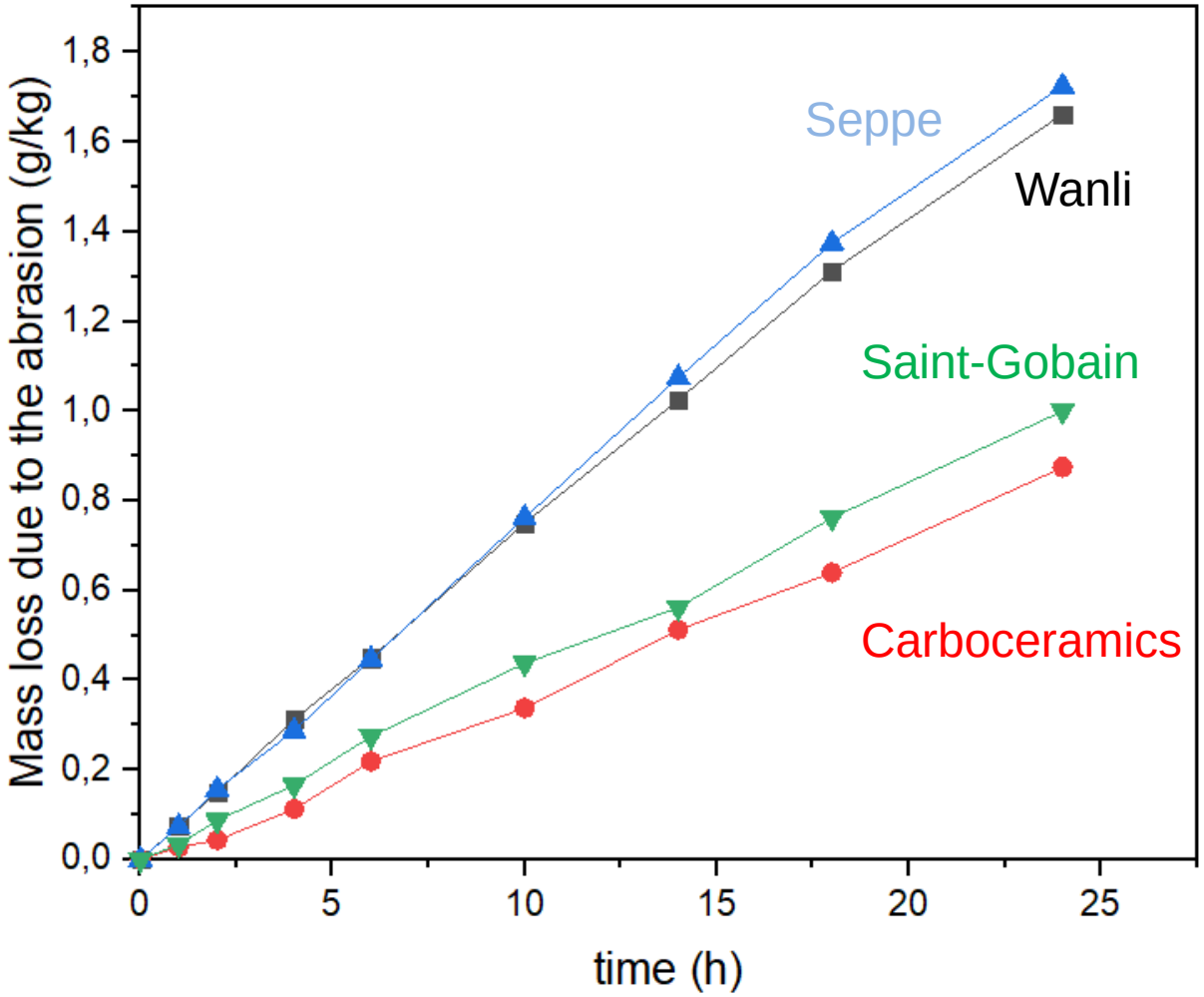
Higher viscous flow temperature

Heat capacity of the proppants



- The lower limit is 1 J/g-K for the enhanced energy storage density
- All proppants are promising
- Carboceramics has the highest value

Assessment of the (RT) abrasion resistance of the proppants



- **Wanli** and **Seppe** experience higher mass loss due to the abrasion
- **Saint-Gobain** and **Carboceramics** have high abrasion resistance
- Glass phase, softer than crystalline components , causes lower abrasion resistance

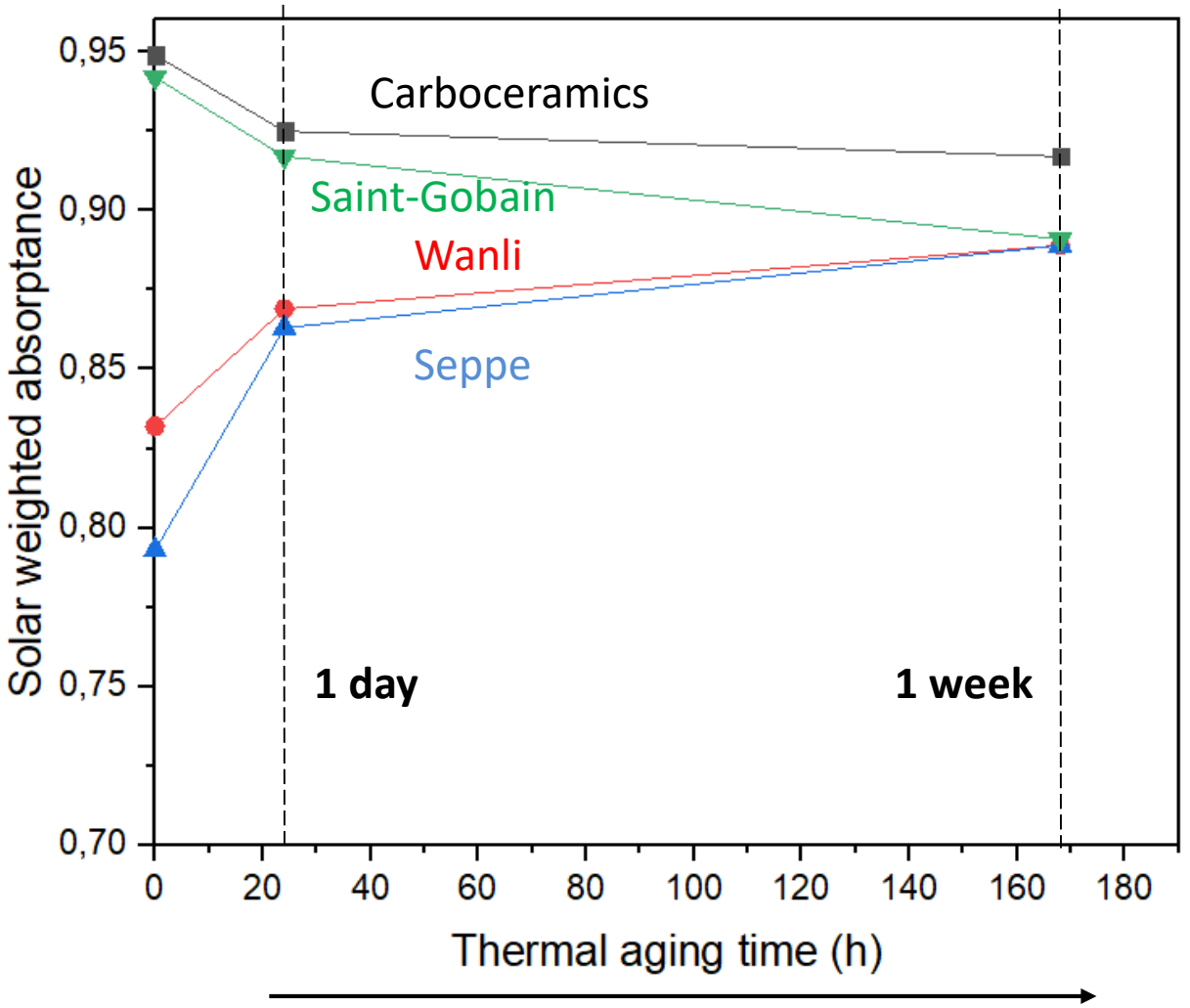
Well crystallized microstructure with minimized glassy components

Higher abrasion resistance

Assessment of the solar absorptance of the proppants

Carboceramics & Saint-Gobain
high initial solar absorptance
(Crystals bearing color giving elements)

Wanli & Seppe
lower solar absorptance
(lack of crystallization of color giving elements)

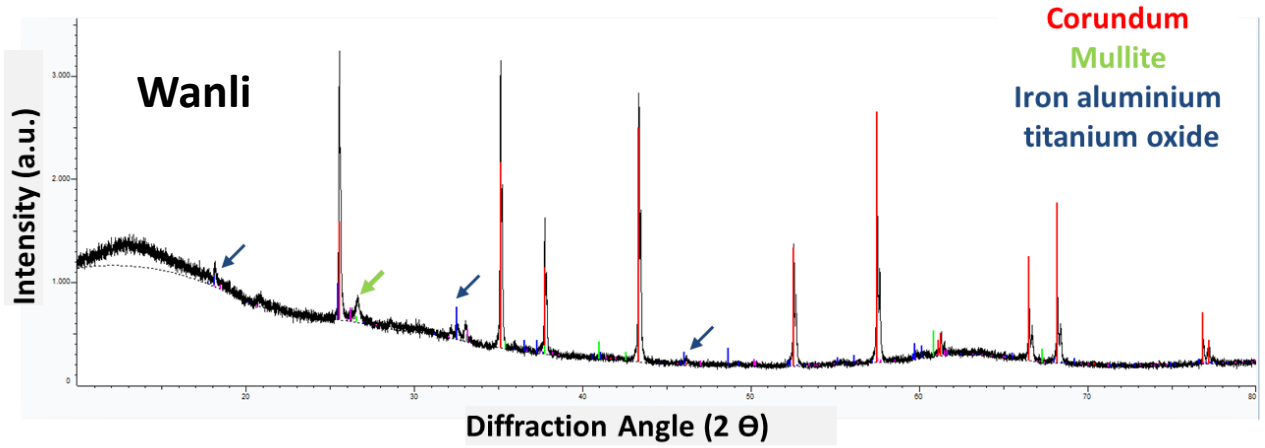


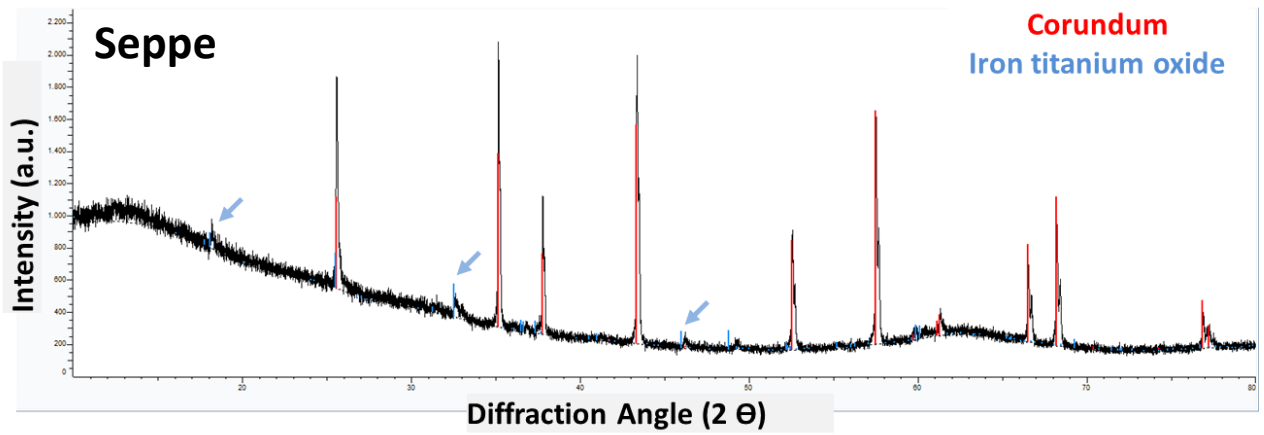
Carbocer: slightly decreasing absorptance but still > 0.9

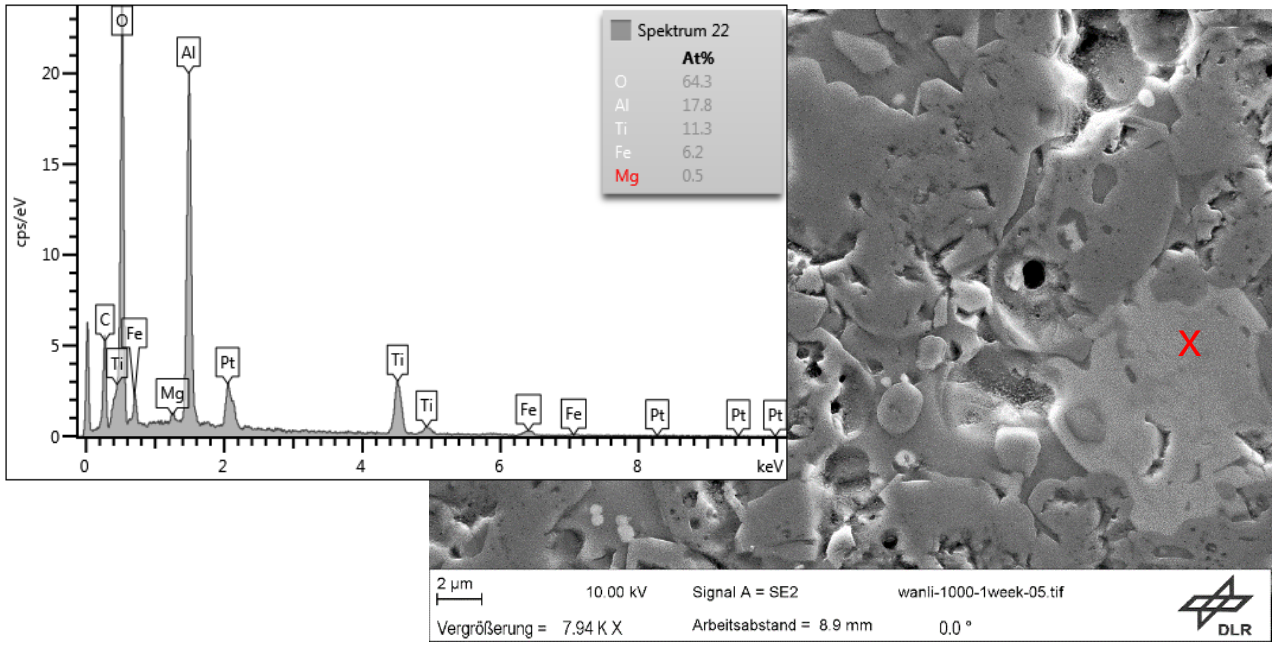
Saint-Gobain: more dramatic decrease

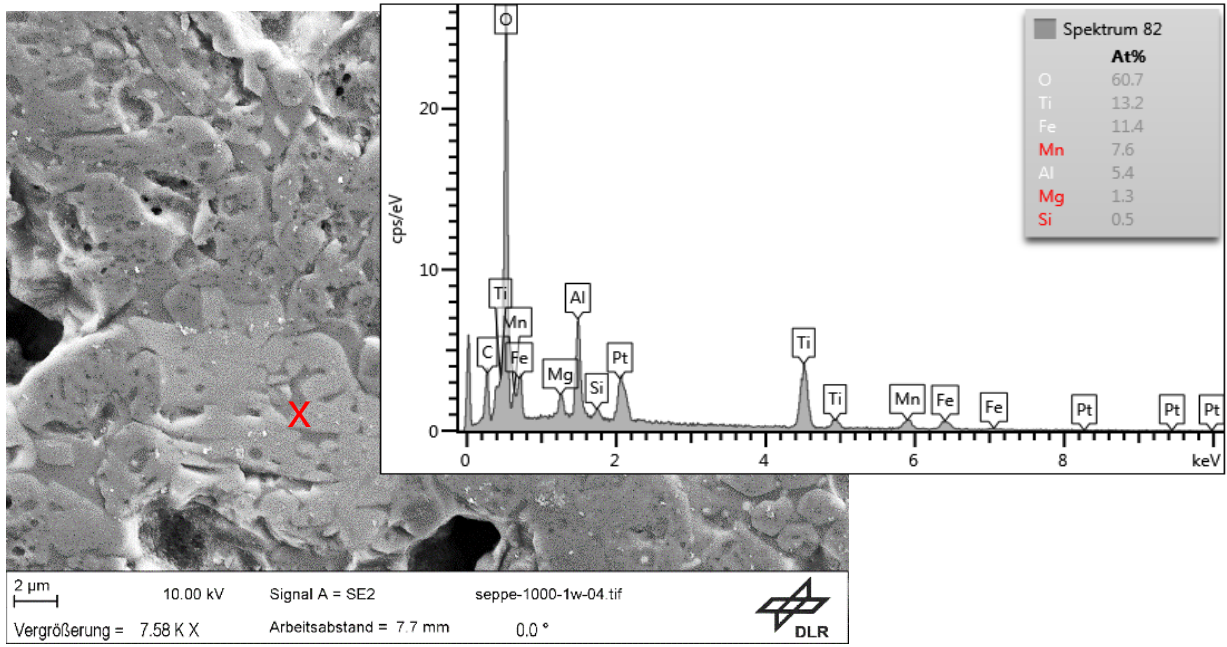
Wanli &Seppe: enhanced absorptsance through aging but still <0.9

Assessment of the microstructure after thermal aging



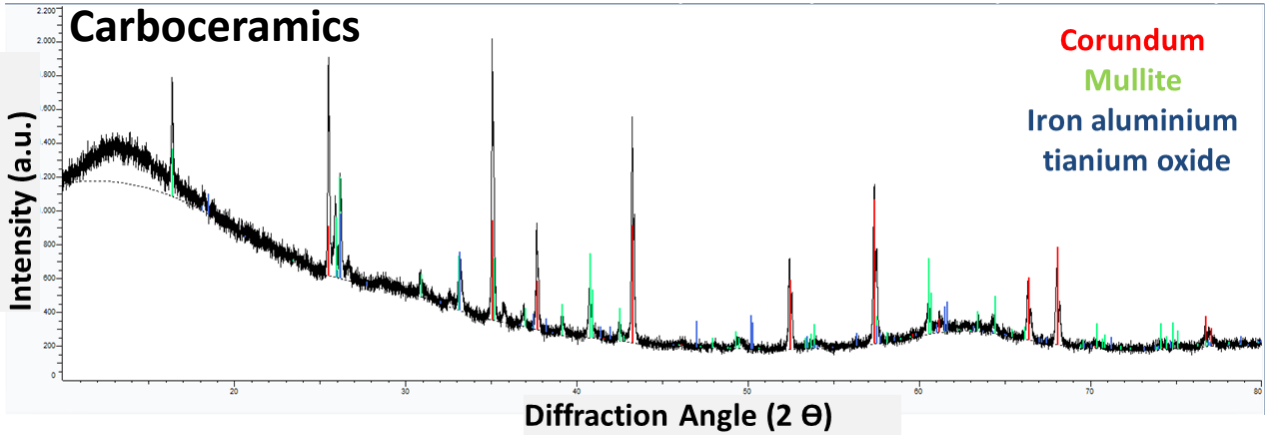


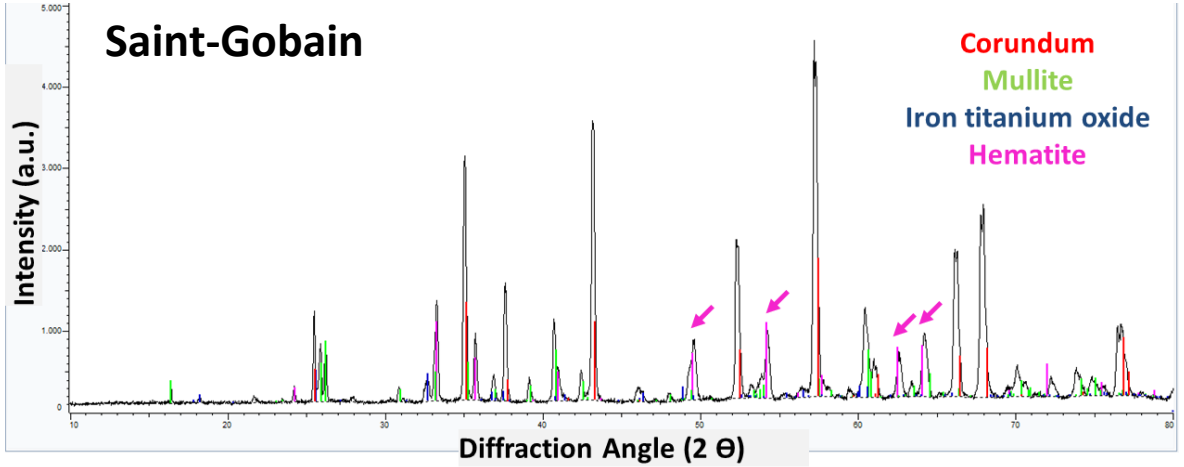


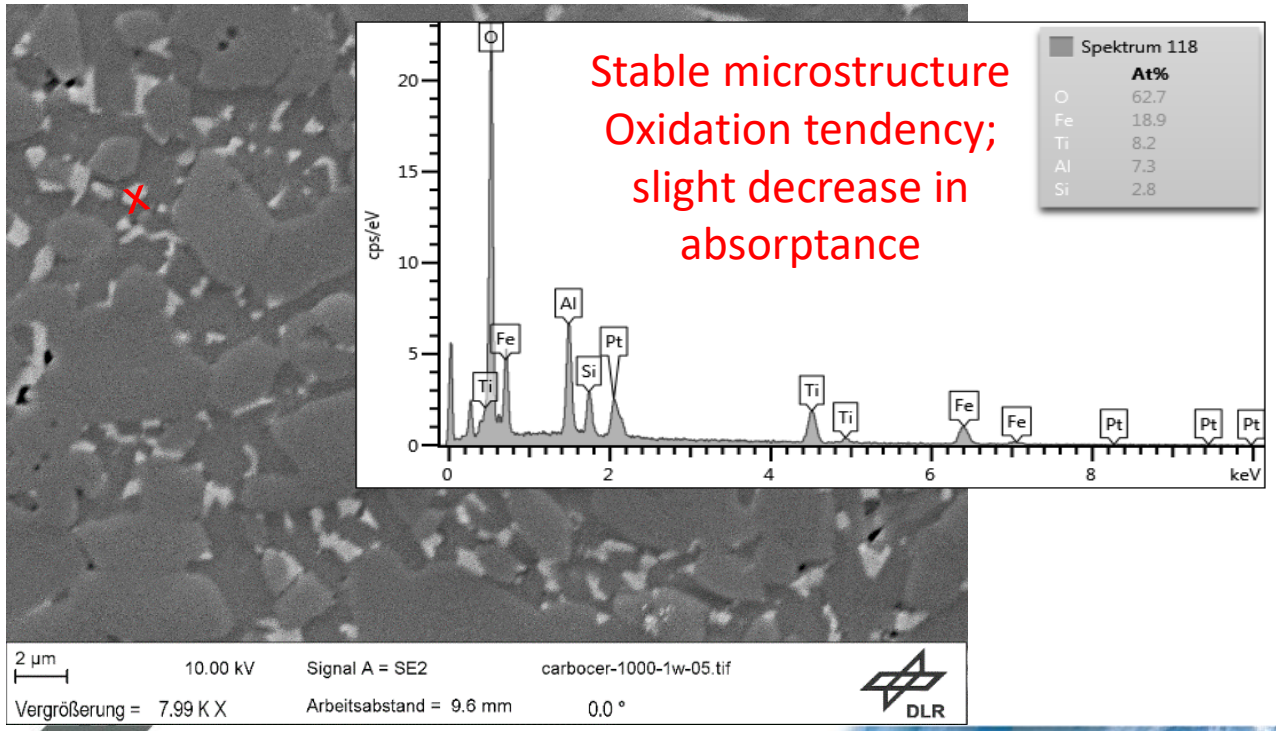


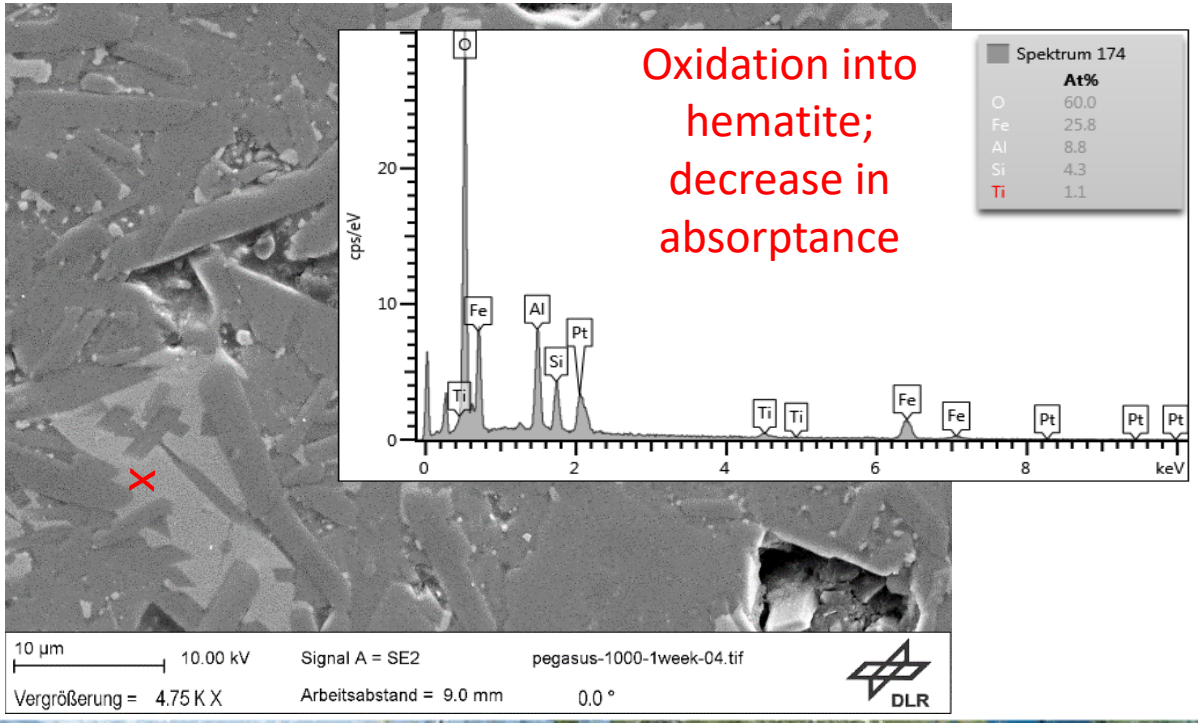
Better crystallization of color giving element bearing phases; enhanced absorptance

Assesment of the microstructure after thermal aging







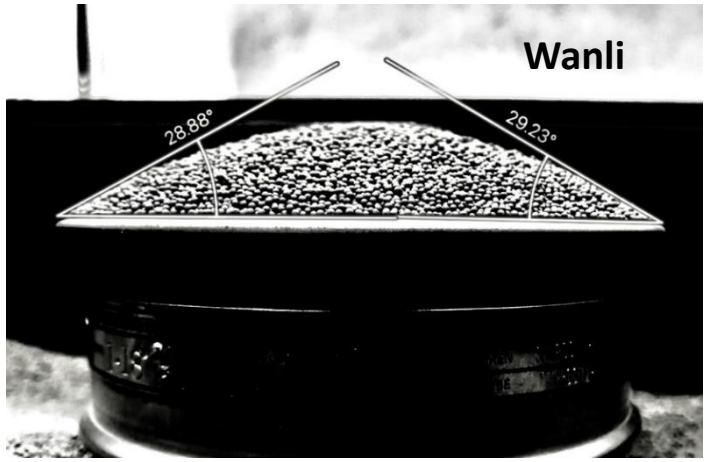


Mass flow rate

Manufacturer	Average mass flow (kg/s)
Carboceramics	**3.30**
Saint Gobain	**3.32**
Wanli	**3.01**
Seppe	2.25

- 3 kg/s is the minimum requirement
- Carboceramics and Saint-Gobain proppants are promising

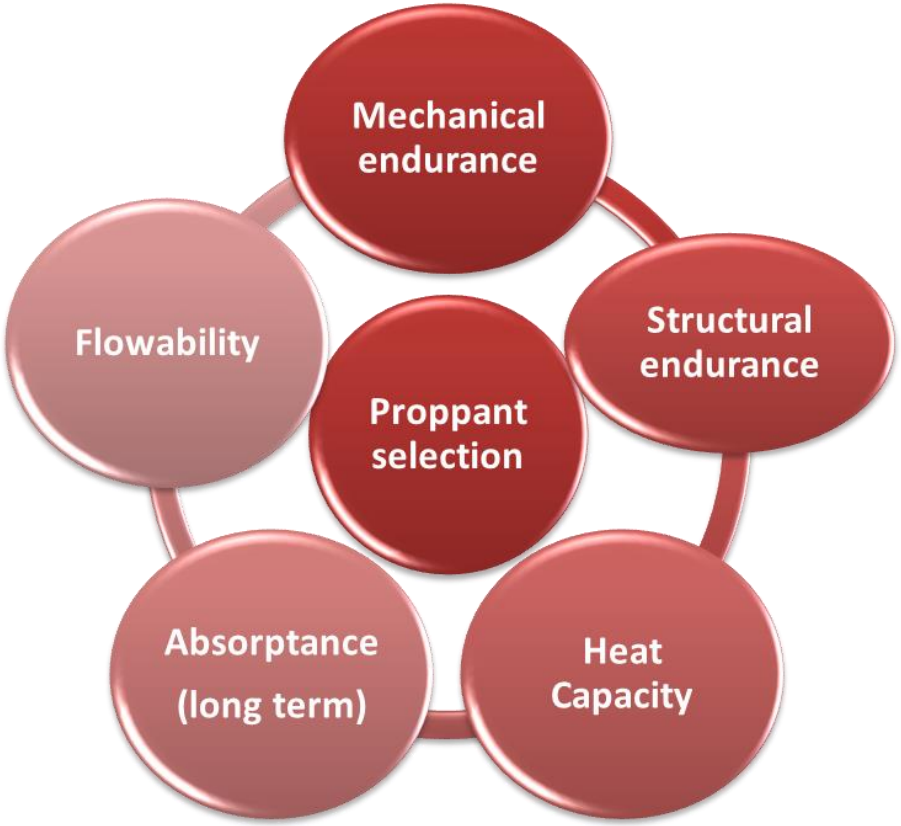
Angle of repose

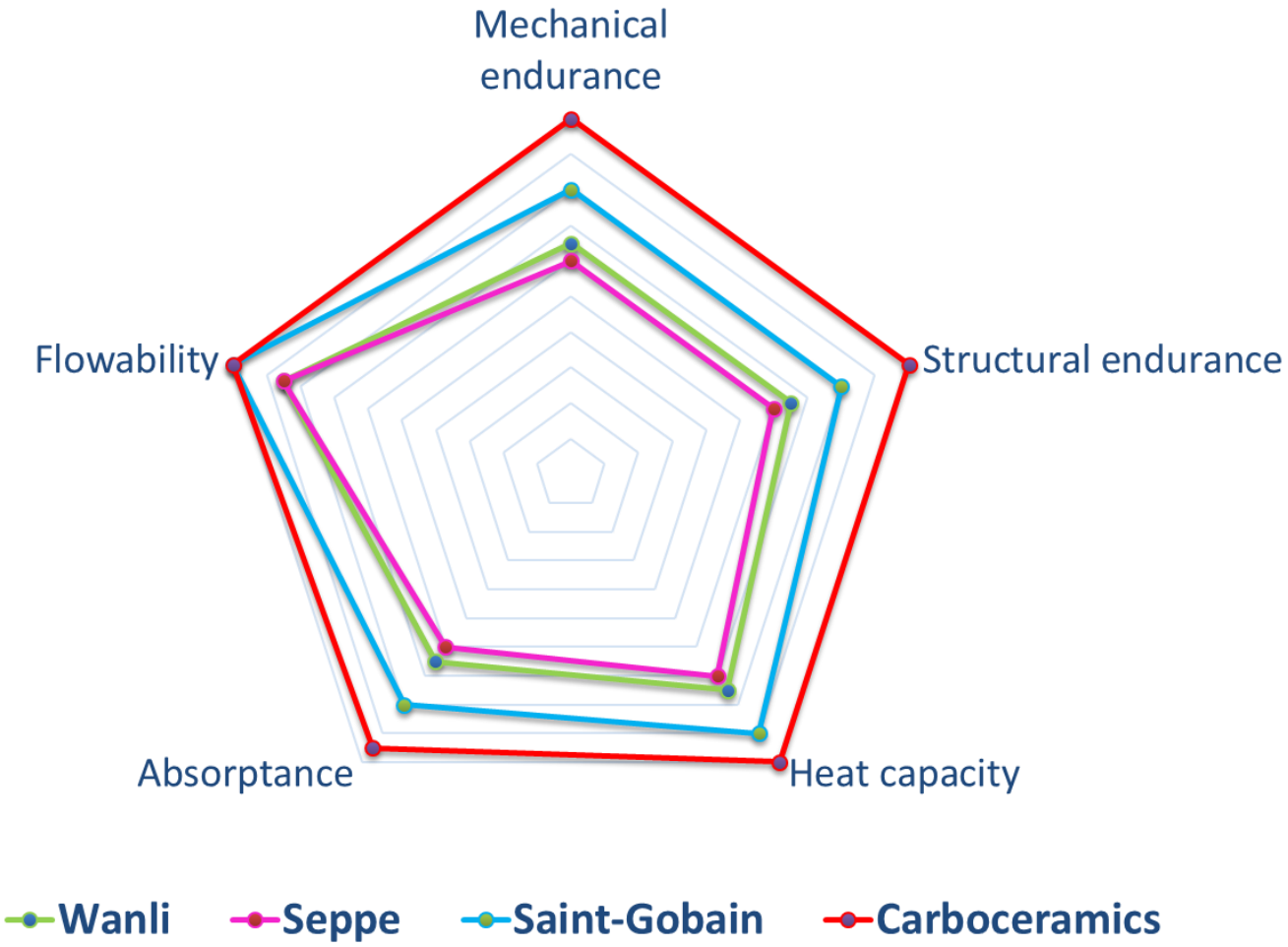


Manufacturer	Angle of repose (˚)
Carboceramics	34.29
Saint Gobain	32.52
Wanli	29.55
Seppe	32.31

- ~ 30˚ is the requirement; All proppants meet the criteria

Summary





- **Carboceramics** is the most promising proppant
- Microstructure plays a cruical role on the application related properties
- Well crystallized components with minimized glass phase provides better properties

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Thank you for your attention!

Q&A

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