Circular options in ceramic materials: refractories

processes

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Article

Recovery of Raw Materials from Ceramic Waste Materials for the Refractory Industry

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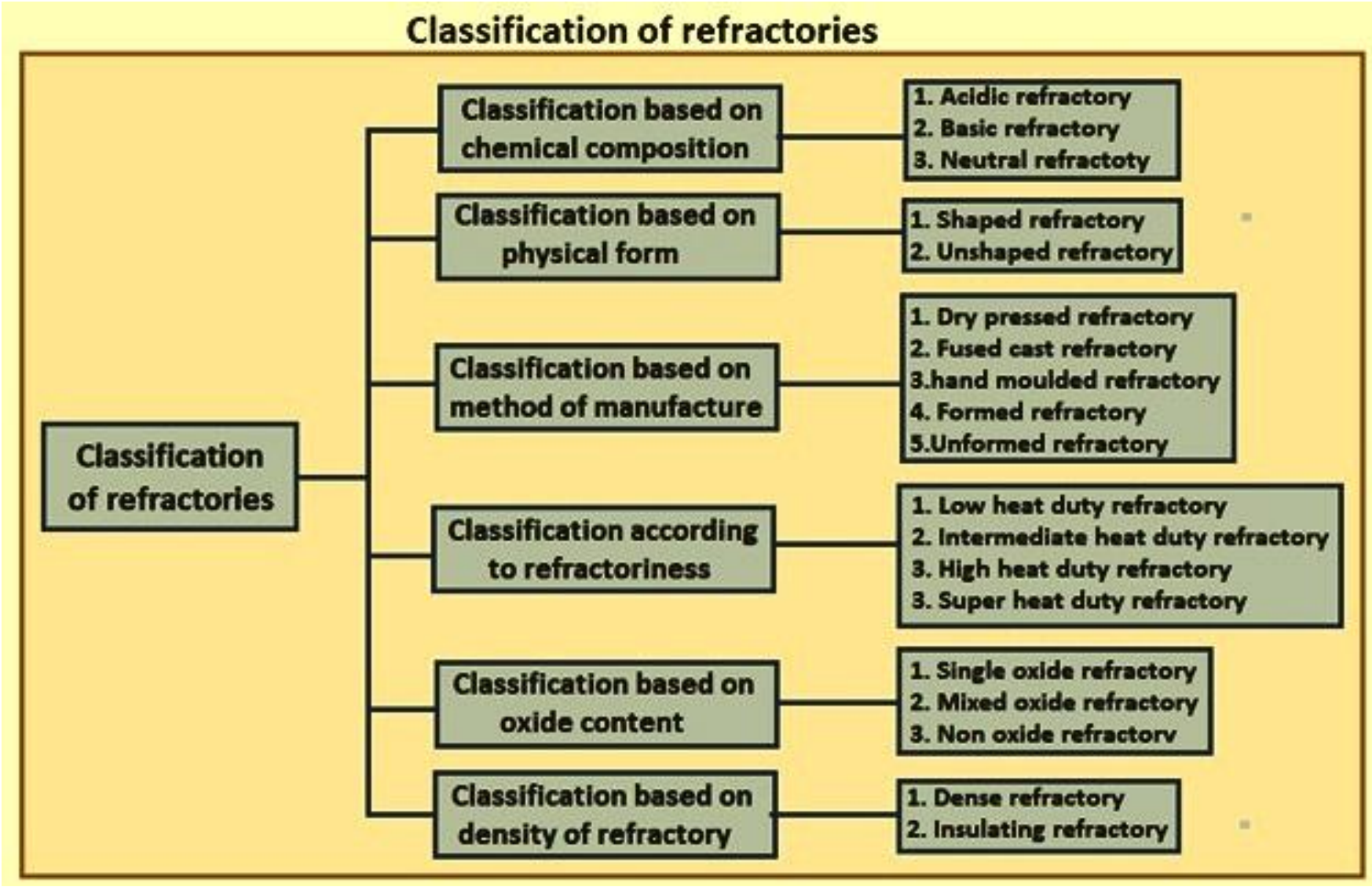
Refractories are materials that are resistant to high temperature, used predominantly as furnace linings for elevated temperature materials processing and other applications in which thermomechanical properties are critical.

Definition taken by: https://www.sciencedirect.com/topics/materials-science/refractory-material#:~:text=Refractories%20are%20materials%20that%20are,which%20thermomechanical%20properties%20are%20critical.

Classification of refractories



Refractory materials

- zero shrinkage/dimensional stability
- high thermal shock resistance
- extremely high thermal stability (melting point > 1500°C)
- chemical resistance and mechanical or temperature dependent strength





Melting points of refractory materials

Elements	Melting point (°C)			
	Oxide	Nitride	Carbide	Boride
Aluminum	2050	2200	2200	–
Silicon	1702	1900[a]	2300	–
Beryllium		2200	2100[a]	–
Magnesium	2800	1500	–	–
Calcium	2600	–	2160	–
Barium	1923	–	–	–
Titanium	1843	2950	3067	3230
Vanadium	–	2177	2648	2673
Chromium	2275	–	1810	2400
Zirconium	2700	2980	3450	3246
Niobium	1512	2400	3400	3273
Molybdenum	–	–	2600	2823
Hafnium	2758	3387	3928	3250
Tantalum	1872	3093	3983	3310
Tungsten	1700[a]	–	2776	2365
Boron	–		2450	2973

a: decomposes

Circular options in ceramic refractory materials

- Products of the refractory industry are key for the production of heavy industry goods such as steel and iron, cement, aluminum and glass.

- Corresponding industries are dependent on thermal processes to manufacture their products, which in turn would not be possible if there were no refractory materials, such as refractory bricks or refractory mixes.

- For the production of refractory materials, primary raw materials or semi-finished products such as corundum (= aluminum oxide, Al_2O_3, with traces of Cr (ruby) and Fe (sapphire)), bauxite (= primary ore of aluminium, mixture of hydrous aluminum oxides, aluminum hydroxides, clay minerals) or zircon ($ZrSiO_4$) are used.

- For example, in 2016 the German steel industry produced a total of 40.2 million t of steel products, requiring 0.5 million t of refractory materials. This means approximately 1 kg of refractory materials were needed to produce 80 kg of steel

Circular options in ceramic refractory materials

- the average lifetime of refractory materials depends on the application and ranges from few days (e.g., purging plugs) to a few weeks (e.g., steel-casting ladles and converters) to long-term applications from one to several years (e.g., converters and heat exchangers/ preheaters)

- use of the innovative process of electrodynamic fragmentation as a recycling strategy for refractory waste products in order to obtain regenerates with a high chemical purity.

- with these high-quality regenerates, new sources of raw materials for the refractory industry could be made accessible, and thus primary resources are conserved.

- the increased use of such high-purity refractory regenerates would lower the cost of refractory materials and could reduce dependencies on world markets.

Electrodynamic fragmentation

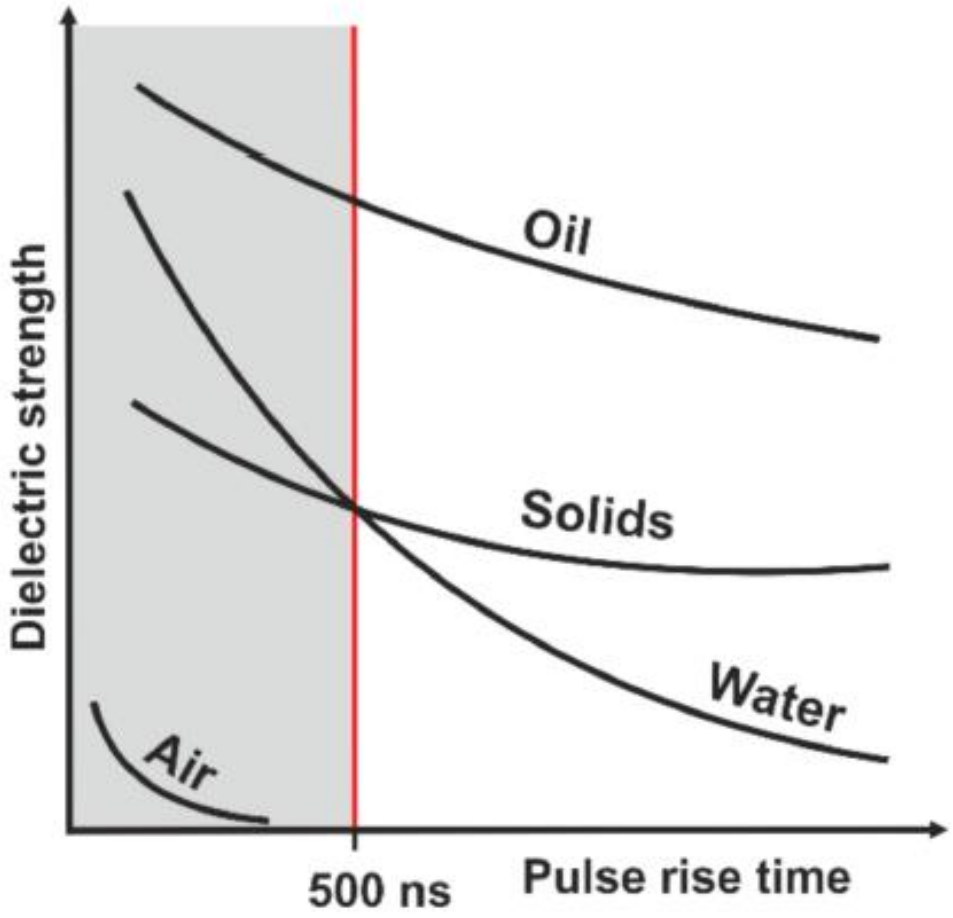
- electrodynamic fragmentation is a technique using pulsed power discharges to separate bulky multi-phase material selectively along grain boundaries.
- the discharge has to take place underwater to enable the solid material to be penetrated. thus, the whole approach is a “wet process”.
- the potential of this pulsed power processing approach was demonstrated for the recycling of waste concrete
- the method itself was first investigated and described at the University of Tomsk in the late 1940s.

Electrodynamic fragmentation

- the efficiency of the method is the higher the more electrical discharges are generated over time
- whether an electrical discharge can penetrate a material or not depends on the dielectric strength* of the given material.
- the dielectric strength of a material is not a constant but varies in dependency with the slew rate and therefore the length of a discharge.
- at a pulse rise time lower than 500 nanoseconds, the dielectric strength of water is higher than that of solid material.

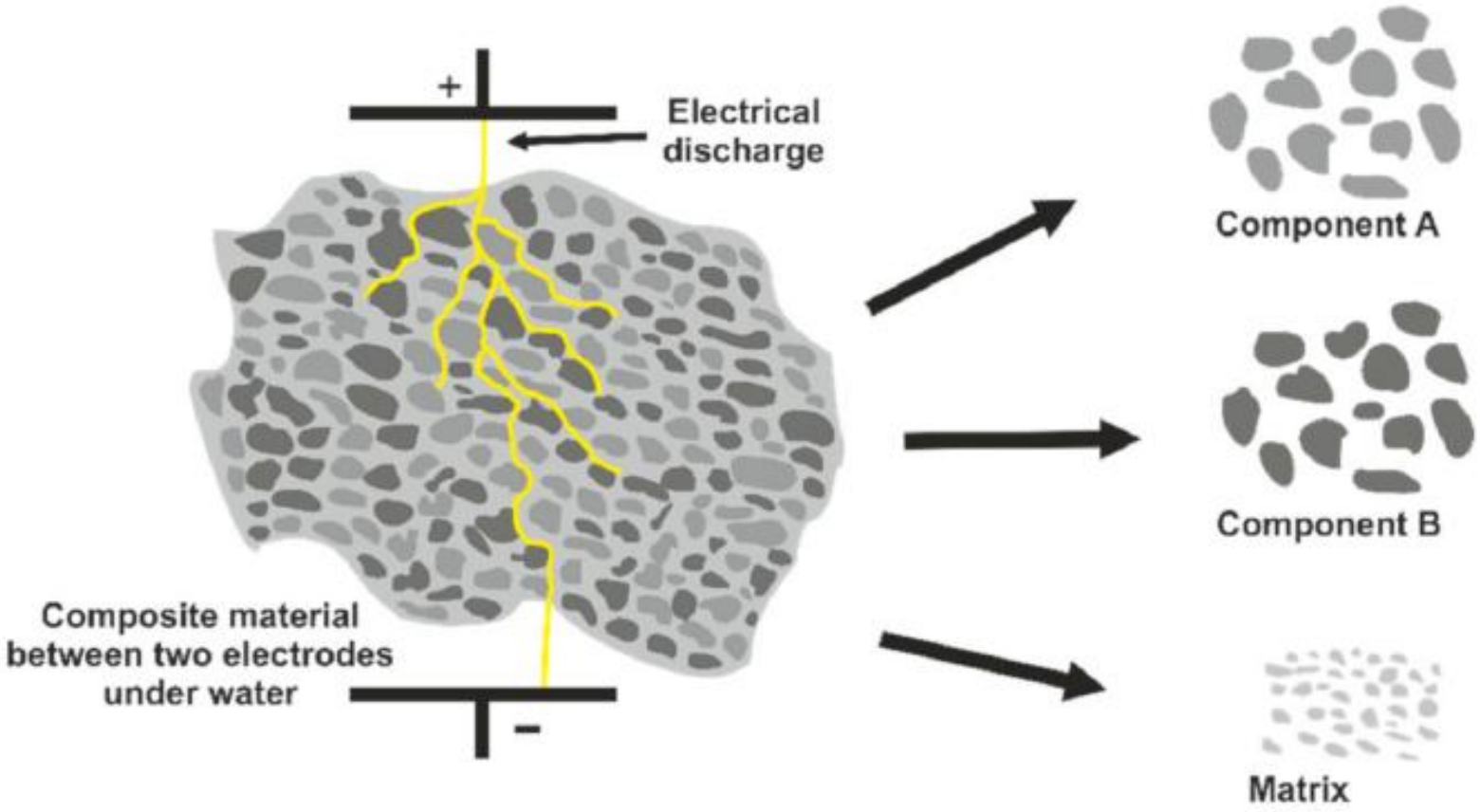
* Dielectric strength is measured as the maximum voltage required to produce a dielectric breakdown through a material. It is expressed as Volts per unit thickness. For a plastic material the dielectric strength varies from 1 to 1000 MV/m.

Electrodynamic fragmentation



Dielectric strength of different materials as a function of the pulse rise time
Source of the figure: Processes **2021**, 9, 228

Electrodynamic fragmentation



Principle of electrodynamic fragmentation of a composite material
Source of the figure: Processes **2021**, 9, 228

use of the regenerated materials

Sample	Material	Potential Regenerates
RefMat-1	Sintered brick for inlet chambers for rotary kilns	Bauxite, zirconia-alumina fused grain (ZAC)
RefMat-2	Corundum stone for aluminum melting furnace	White corundum
RefMat-3	Functional refractory ceramic from the steel industry	Tabular alumina, white corundum

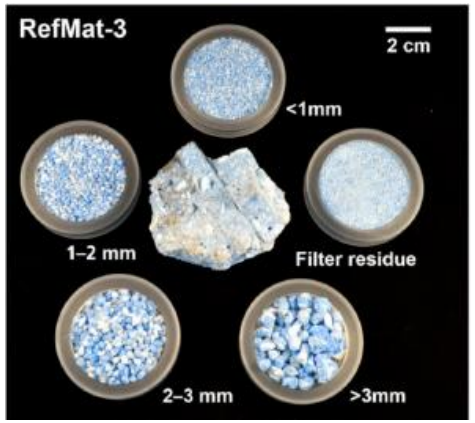
the chemical composition of the regenerates does not differ greatly from the primary material.

the regenerates were used in new refractory ceramics

during the production of the different mixtures it was found that the rheology, and thus the workability of the fresh mixtures, did not change and was absolutely comparable to the reference mixtures.

the important factor here was to reach a comparable flow behavior and thus a comparable workability without changing the water demand

is possible to recover high-quality secondary raw materials for the refractory industry and thus realize a high recycling rate for the material itself.



Sample material RefMat-3 before (central) and after fragmentation and subsequent classification by grain size.

Principle of electrodynamic fragmentation of a composite material
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Electrodynamic fragmentation

The following slides have been already discussed for the composite recycling. They are left here only as reminder

Electrodynamic fragmentation

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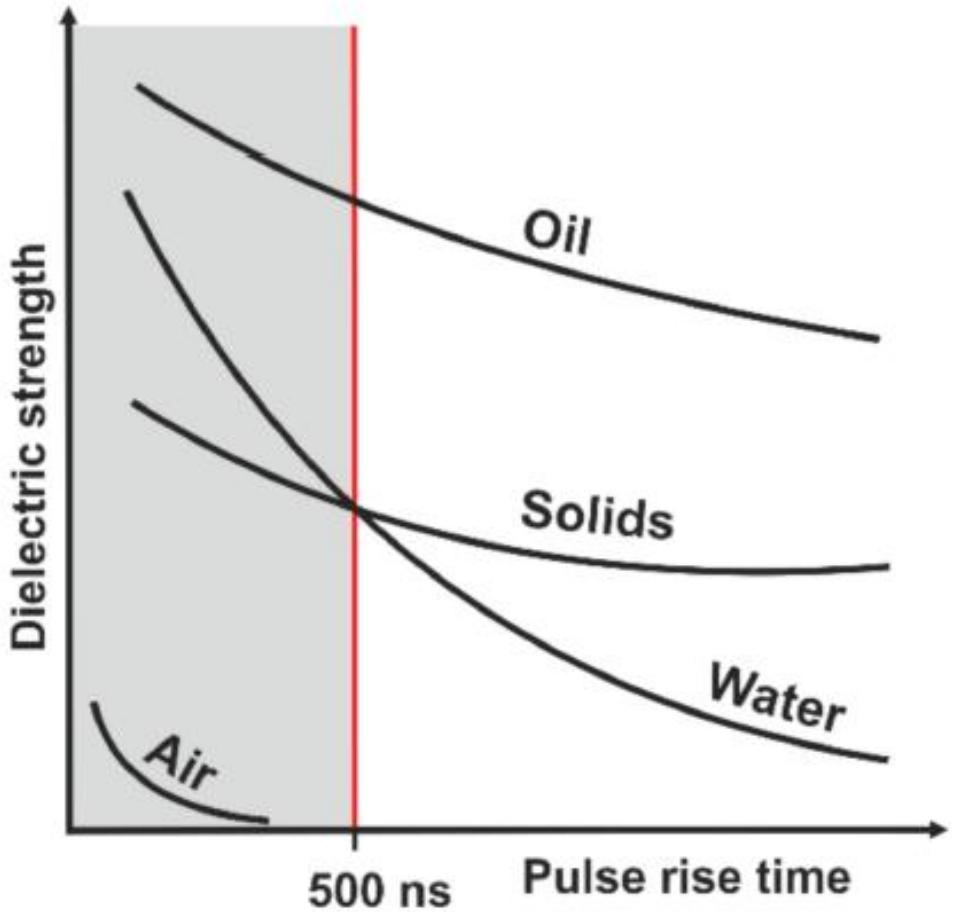
Electrodynamic fragmentation



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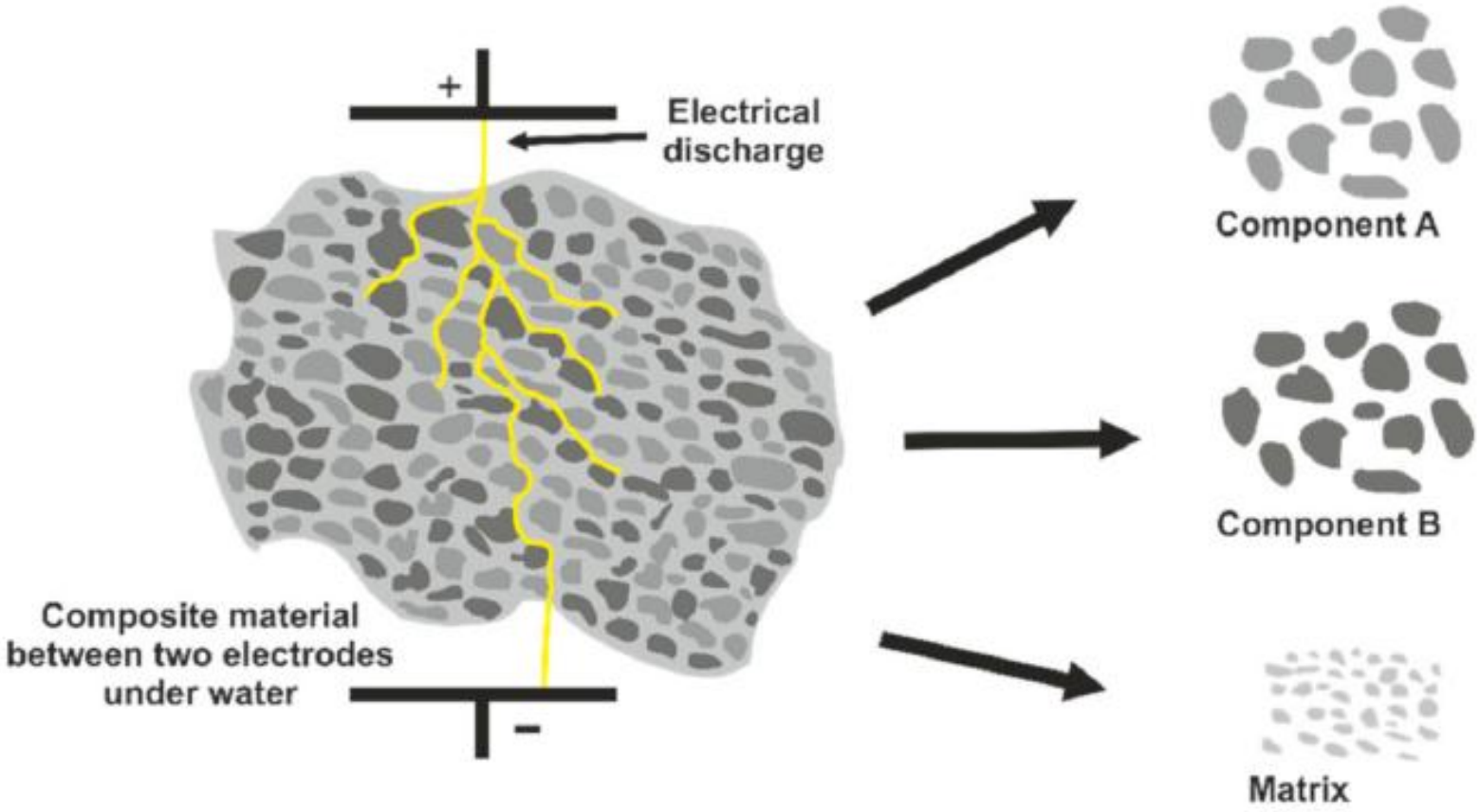
Electrodynamic fragmentation



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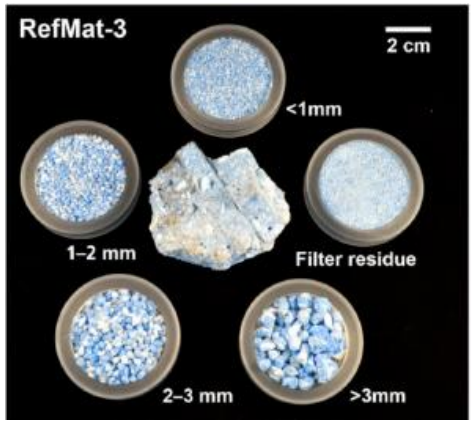

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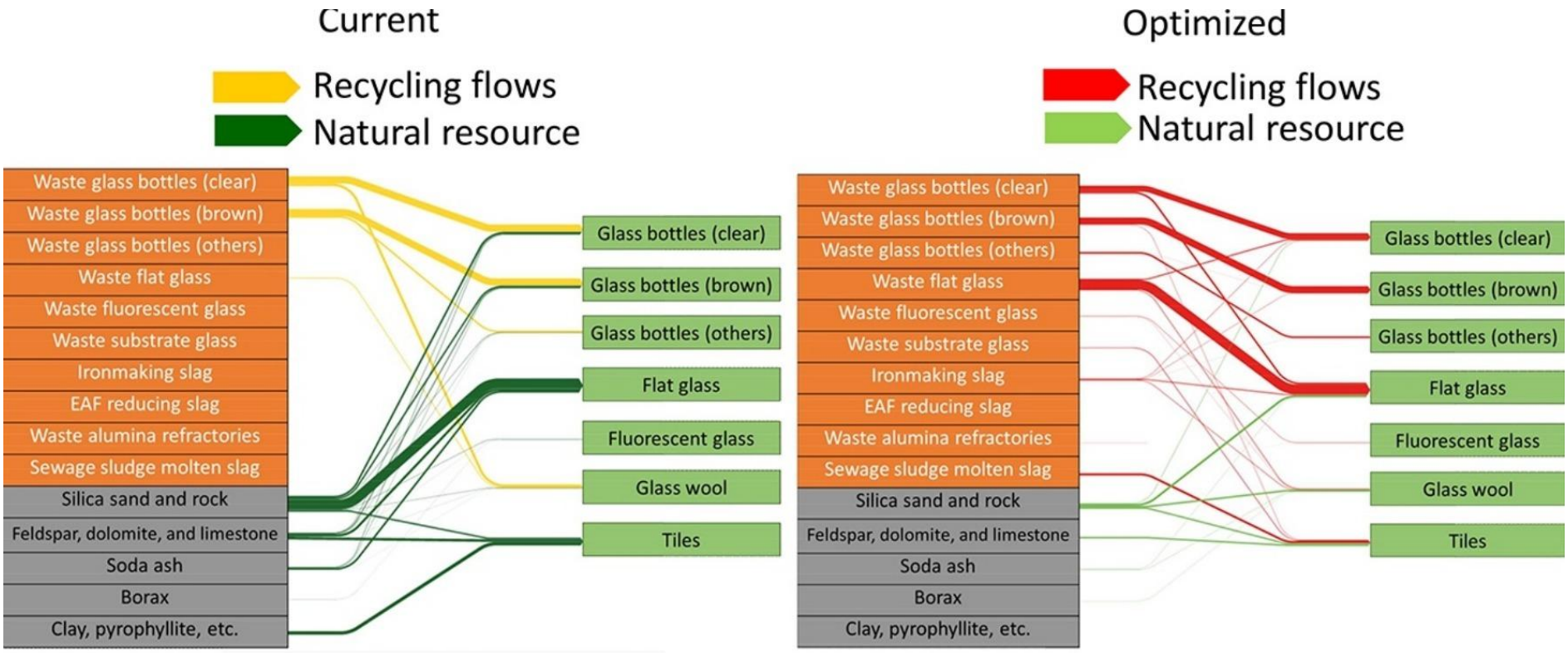
Circular options in ceramic/glass materials



Perspective evolution of the technologies