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Reuse applications for the fine fraction of WtE bottom ash

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Outline of Presentation

- **Introduction:**
  - ➢ **Circular economy**
  - ➢ **Sustainable waste management**
  - ➢ **Waste-to-Energy in circular economy**
- **Production of sintered ceramics:**
  - ➢ **Material characterisation**
  - ➢ **Ceramic processing optimisation**
  - ➢ **Leaching behaviour during processing**
  - ➢ **Effect of ash variability**
  - ➢ **Cost analysis**
- **Production of foamed materials:**
  - ➢ **Effect of rapid sintering**
- **Conclusions**

Circular economy: The concept

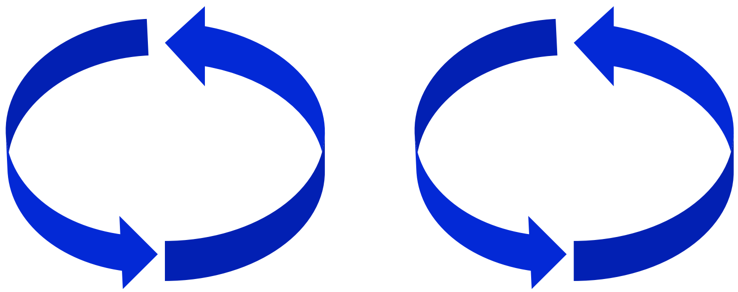
Linear economy

EXTRACT-> PROCESS -> MANUFACTURER ->
CONSUMER -> WASTE DISPOSAL

WASTE

Mixed technical and biological materials

Circular economy



Technical nutrients

Biological nutrients


0%
20%
40%
60%
80%
100%
Austria
Germany
Netherlands
Belgium
Switzerland
Singapore
Sweden
Taiwan
Denmark
Japan
Norway
Korea
Luxembourg
France
E.U. (27 countries)
United Kingdom
Finland
Italy
Ireland
Slovenia
Australia
Spain
Portugal
United States
Hungary
Czech Republic
Canada
Poland
Iceland
Estonia
Cyprus
Greece
China
Slovakia
Malta
Latvia
Lithuania
Russia
Romania
Brasil
Turkey
%Recycled/composted
% Landfilled
%WtE

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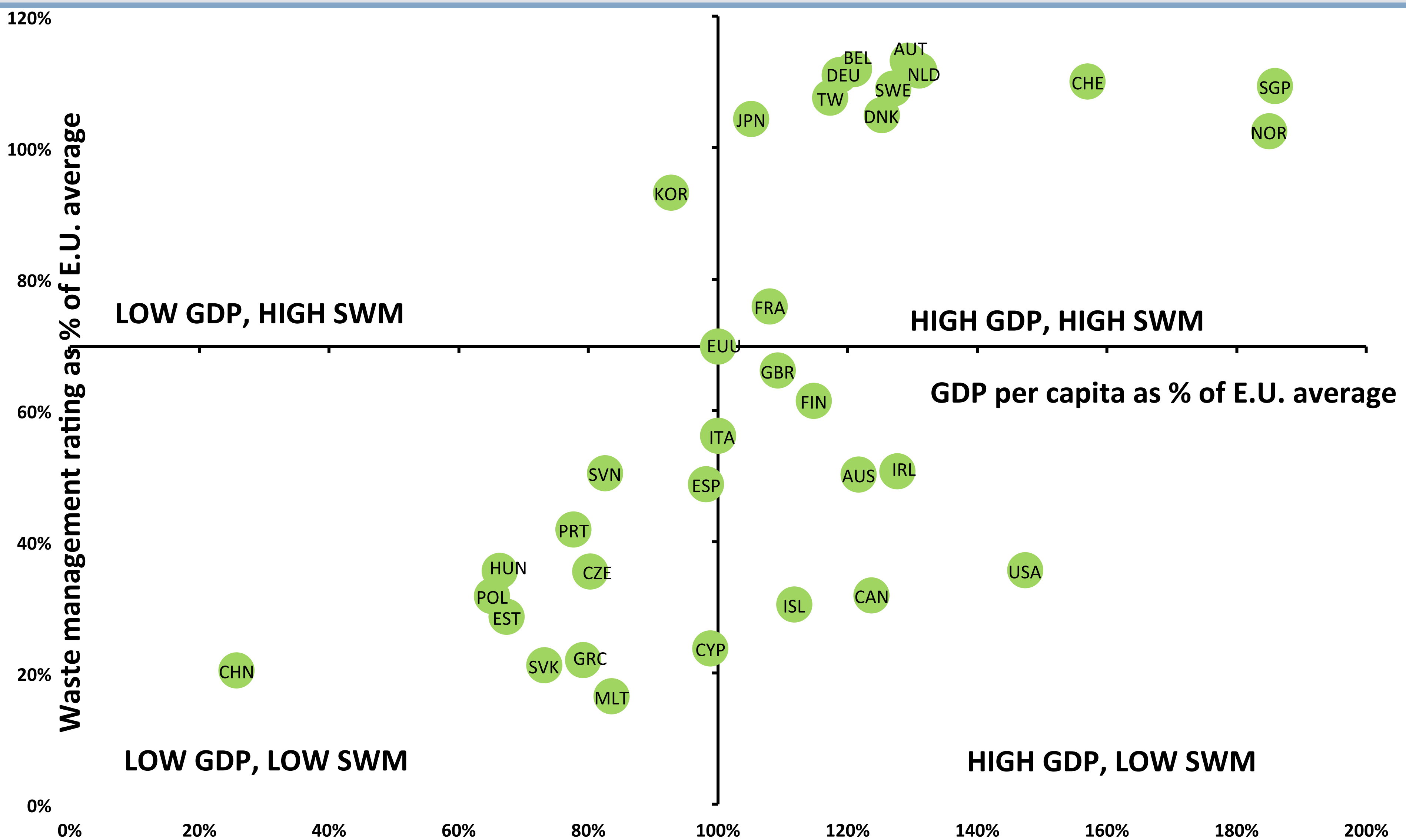
Sustainable waste management (SWM) index vs per capita GDP



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WtE and circular economy

Combustion

Waste to Energy

Flue Gas

Bottom Ash
150-250 kg/tonne MSW

Air Pollution Control Residues
25-35kg/tonne MSW

Resources from Waste

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WtE bottom ash recycling plant

Non-Ferrous metals (0.5-2%)

Coarse fraction (10- 15%)

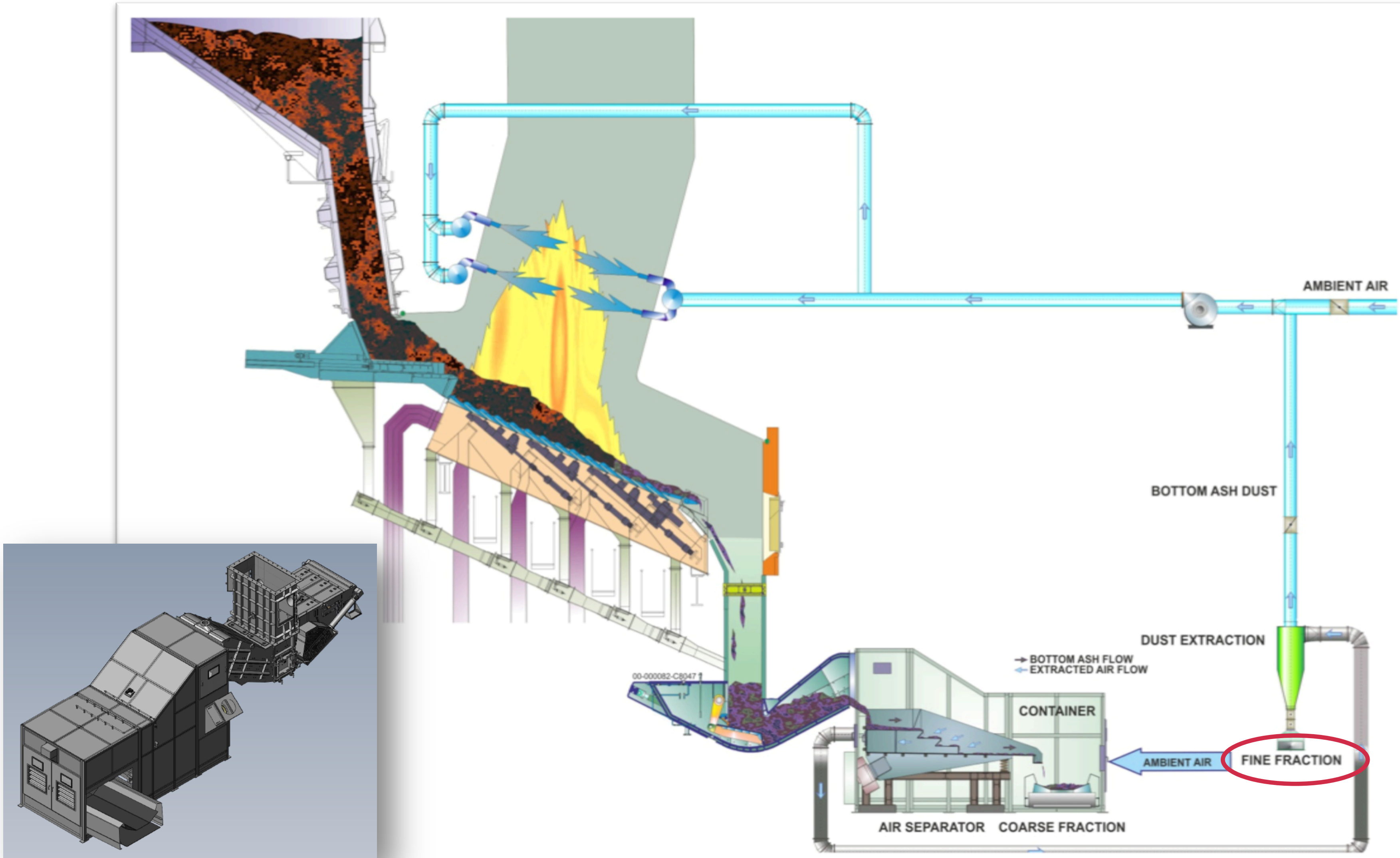
IBA Aggregate (85-95%)

Medium fraction (40-70 %)

Fine fraction (11- 45 %)

Ferrous metals (5-15%)

Monthey dry discharge system- Martin development



Production of sintered ceramics

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Chemical composition of the <500μm IBA (oxide %)

XRF analysis

Oxide	Weight percent %	Oxide	Weight percent %
SiO_2	36.3	MgO	2.0
Fe_2O_3	18.4	TiO_2	1.9
CaO	15.7	P_2O_5	1.9
Al_2O_3	6.4	ZnO	1.8
SO_3	5.7	Na_2O	1.5
K_2O	3.3	CuO	1.3
ClO_2	2.2	Others	1.6
LOI (%)	15.0		

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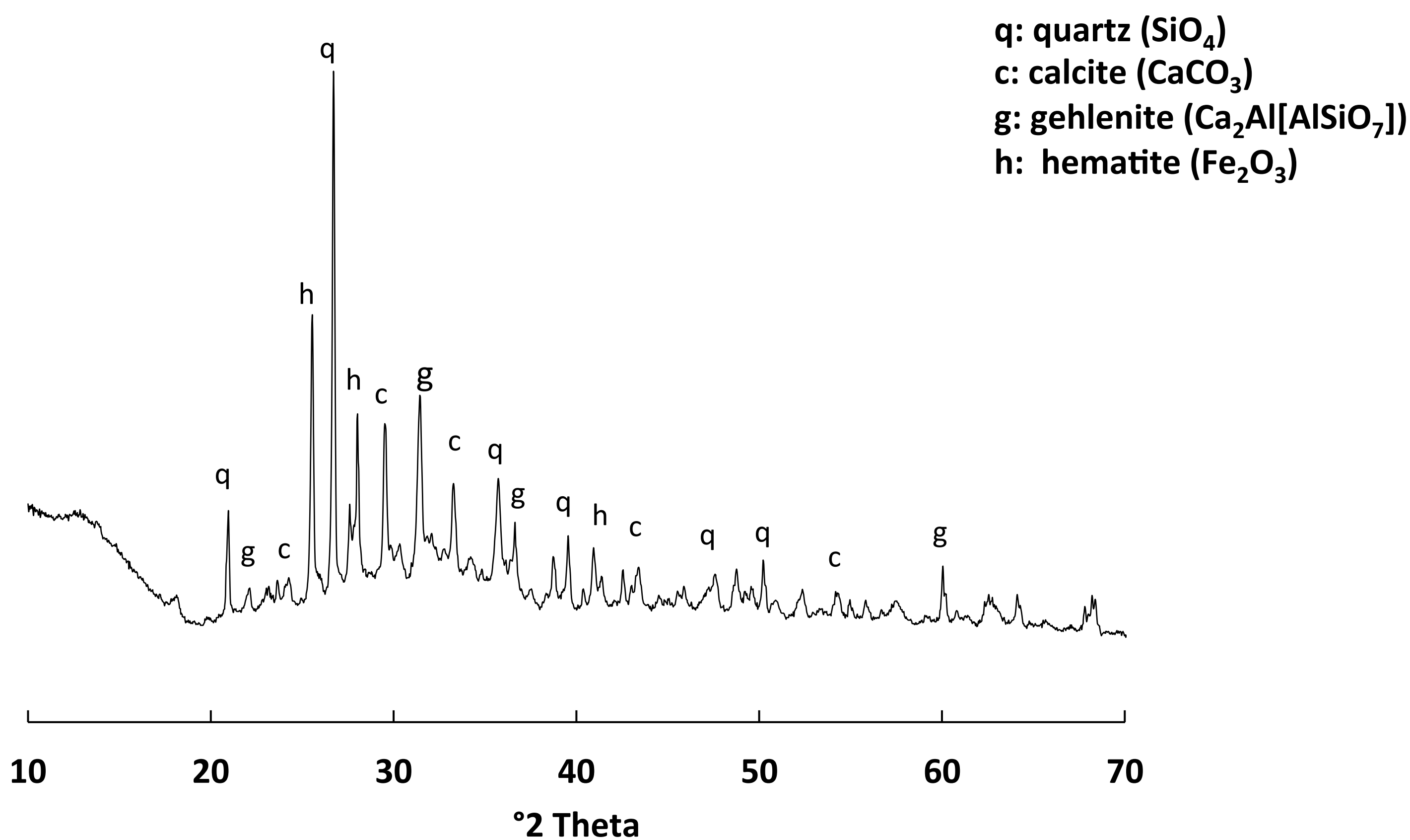
X-ray diffraction : <500µm IBA as-received



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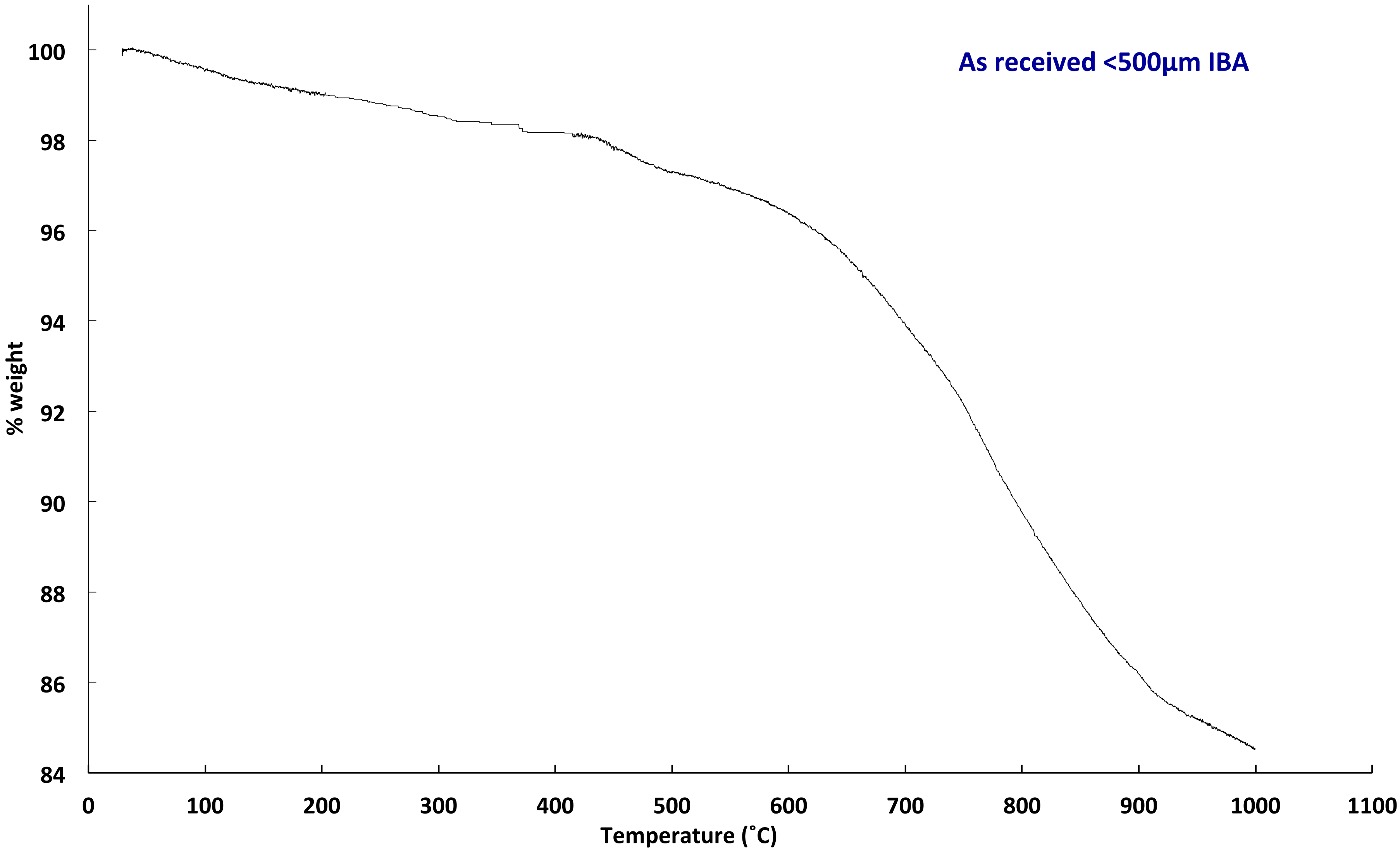
Thermogravimetric analysis (TGA)



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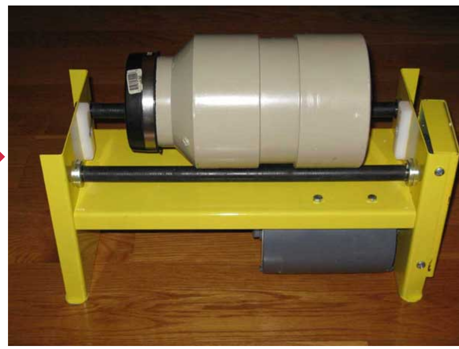
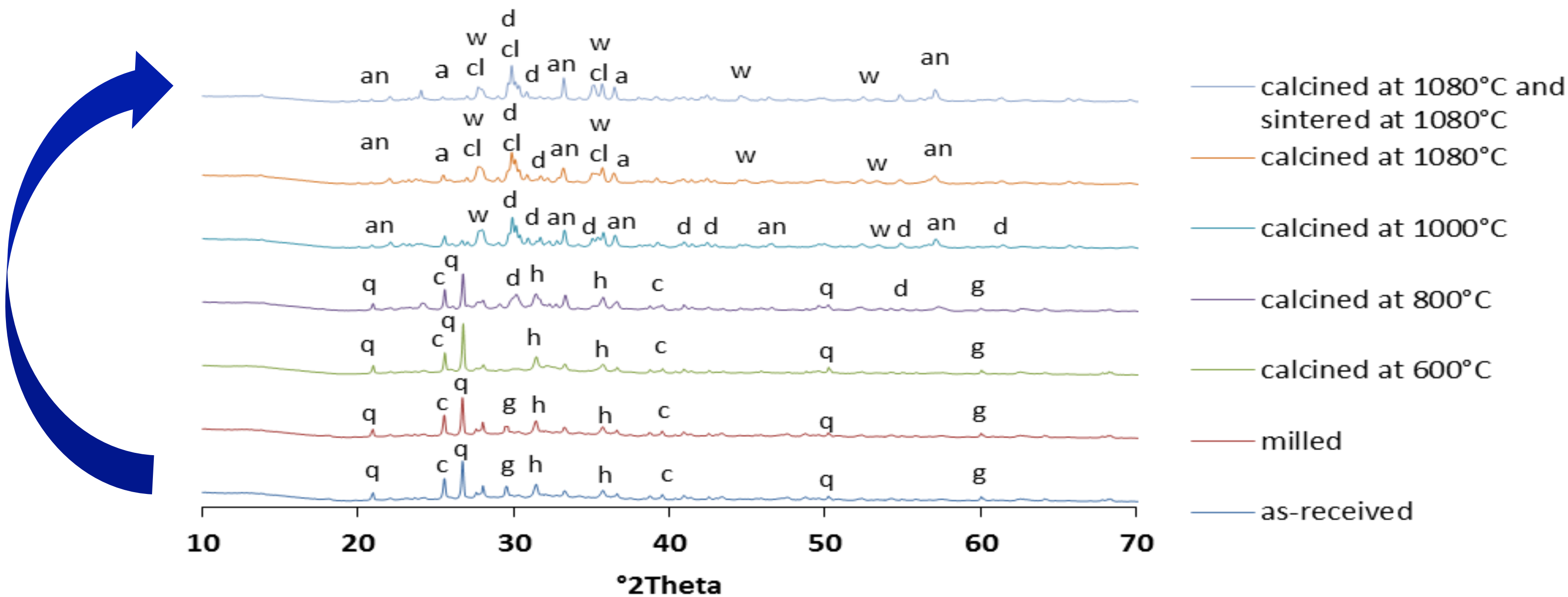
Ceramics manufacturing process

Production of pyroxene powder



Production of sintered ceramics

XRD: changes in crystalline phases during processing

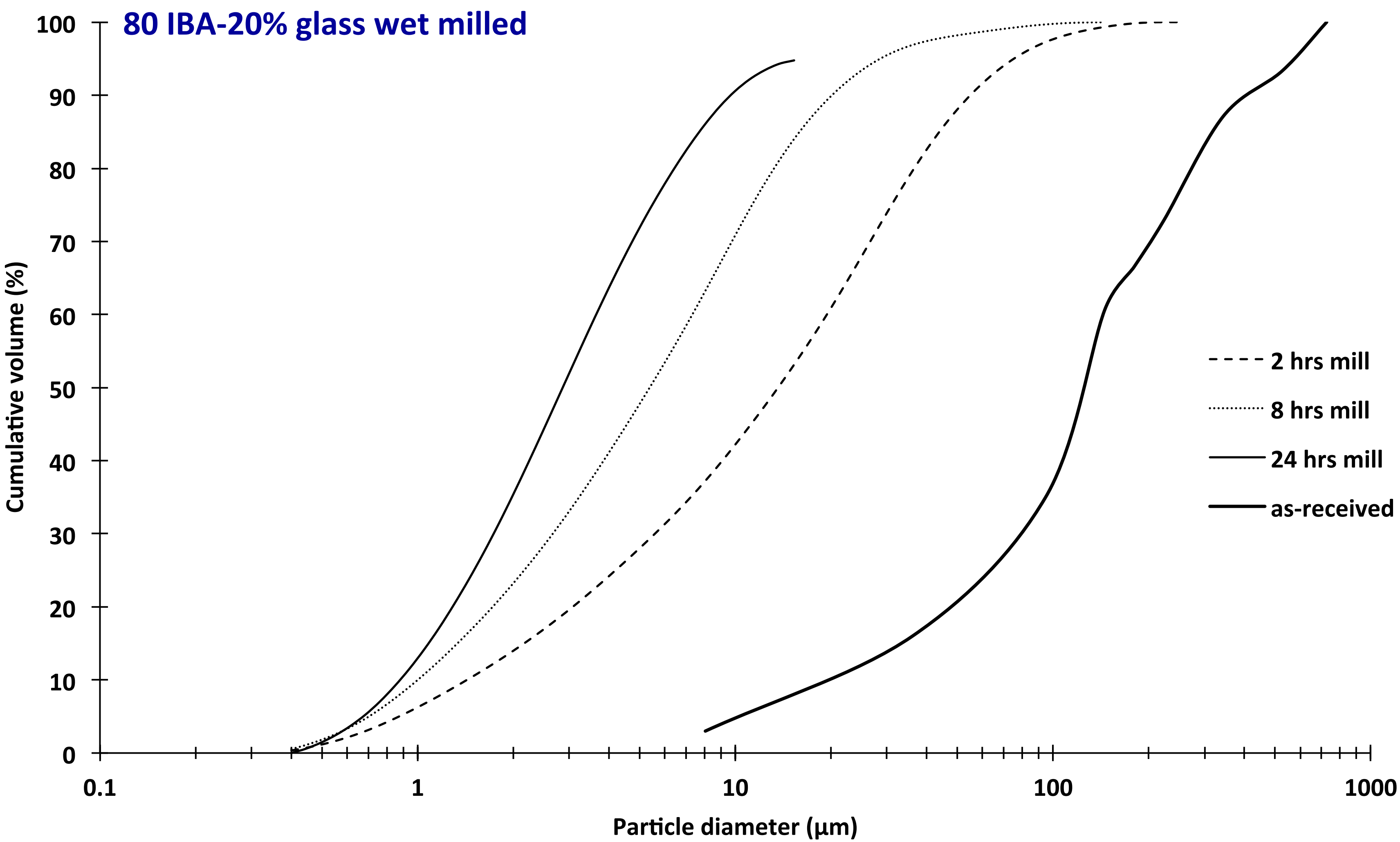


q-quartz (SiO_2); c- calcite ($CaCO_3$); h- hematite (Fe_2O_3); g- gehlenite ($Ca_2Al[AlSiO_7]$)

d-diopside ($MgCaSi_2O_6$) ; cl- clinoenstatite ($Mg_2Si_2O_6$); an-andradite ($Ca_3Fe_2Si_3O_{12}$)

w- wollastonite ($CaSiO_3$); a- albite ($NaAlSi_3O_8$)

Effect of milling time: Particle size analysis



Process optimisation

- Response Surface Methodology (RSM) was used and the Design Expert software
- Describes the relationship between input variables and allows the achievement of optimum processing conditions
- Four steps: model fitting, validation of the model, response surface and optimization
- 200 results from the laboratory work were use as standard points for the system

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Process optimisation: Inputs and outputs

Input variables

Tc: calcining temperature (°C)

Ts: sintering temperature (°C)

IBA/glass content (%)

RSM

Output variables

ρ: density ($g.cm^{-3}$)

WA_{24}: Water absorption (%)

Shrinkage (%)

Appearance

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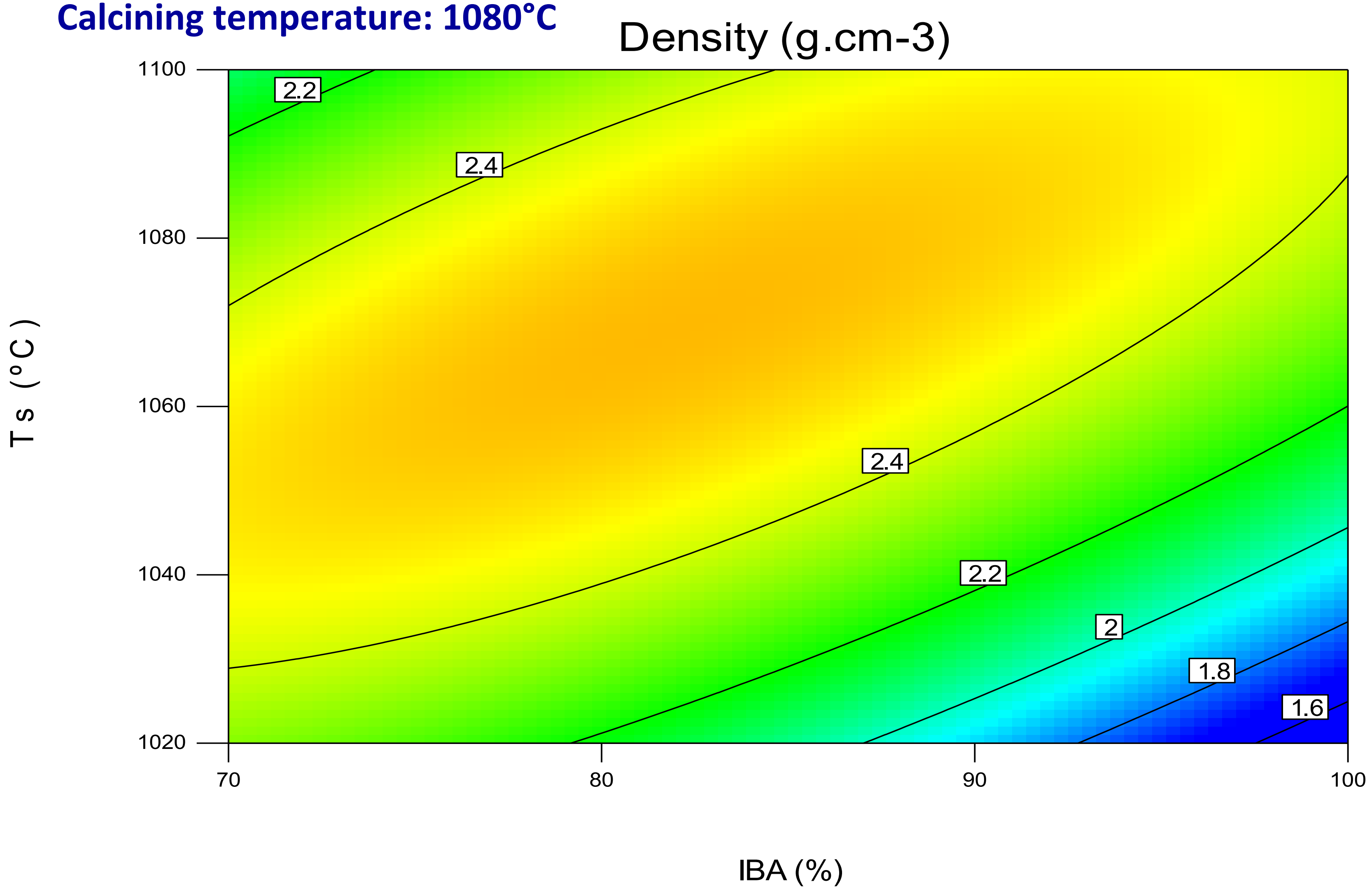
Response Surface for density

Calcining temperature: 1080°C



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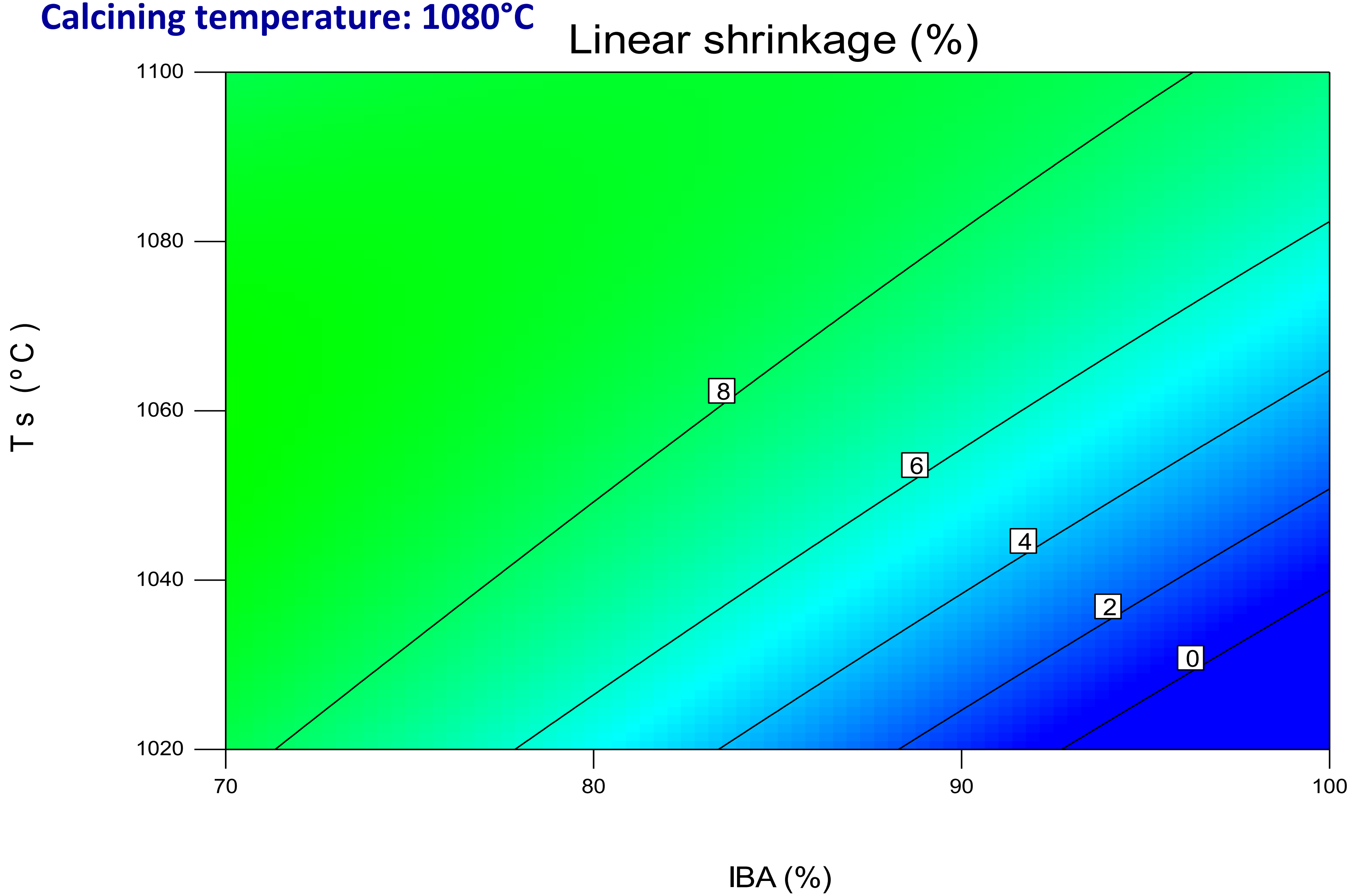
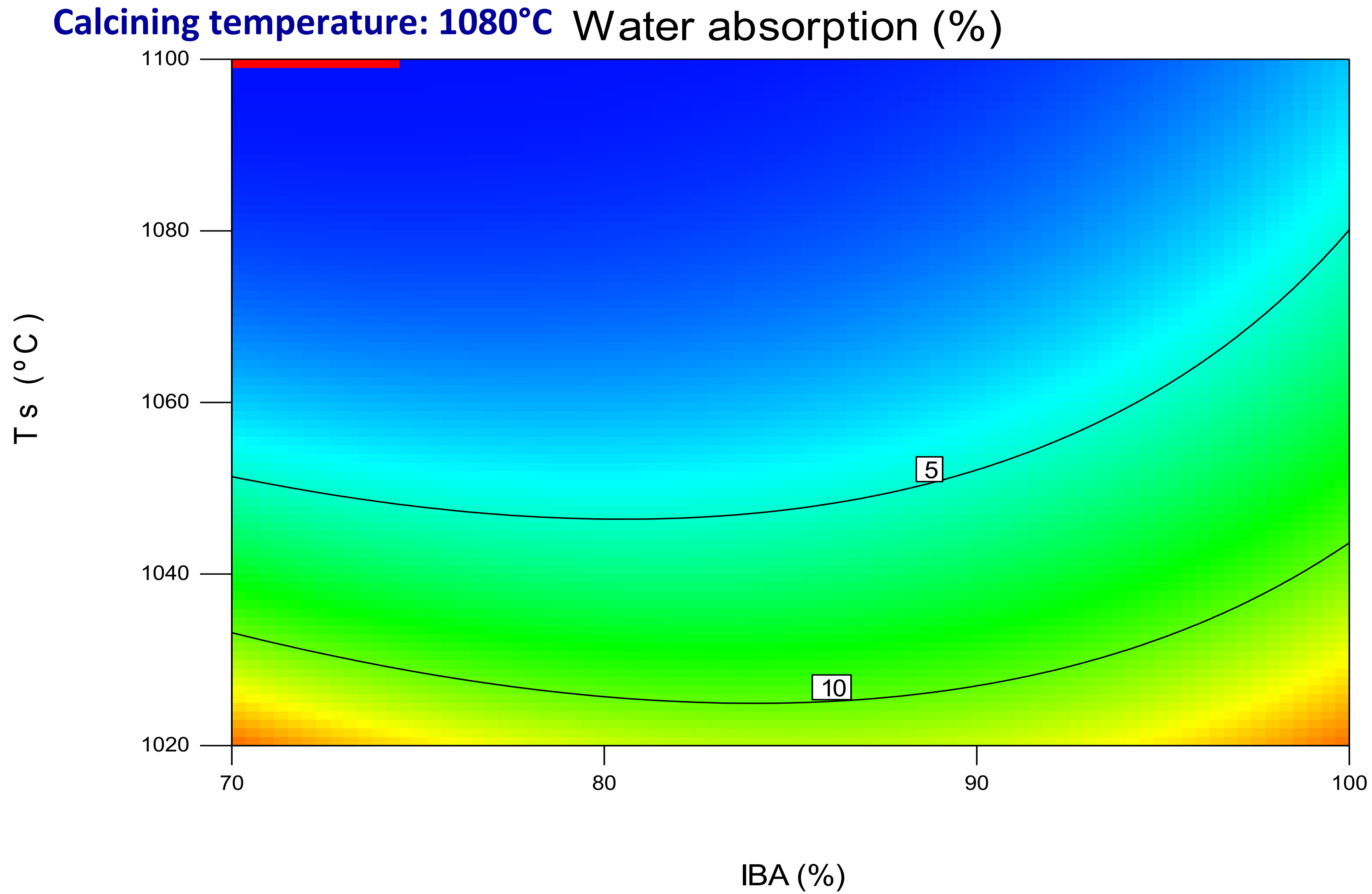
Response Surface for shrinkage

Calcining temperature: 1080°C



Response Surface for water absorption

Calcining temperature: 1080°C

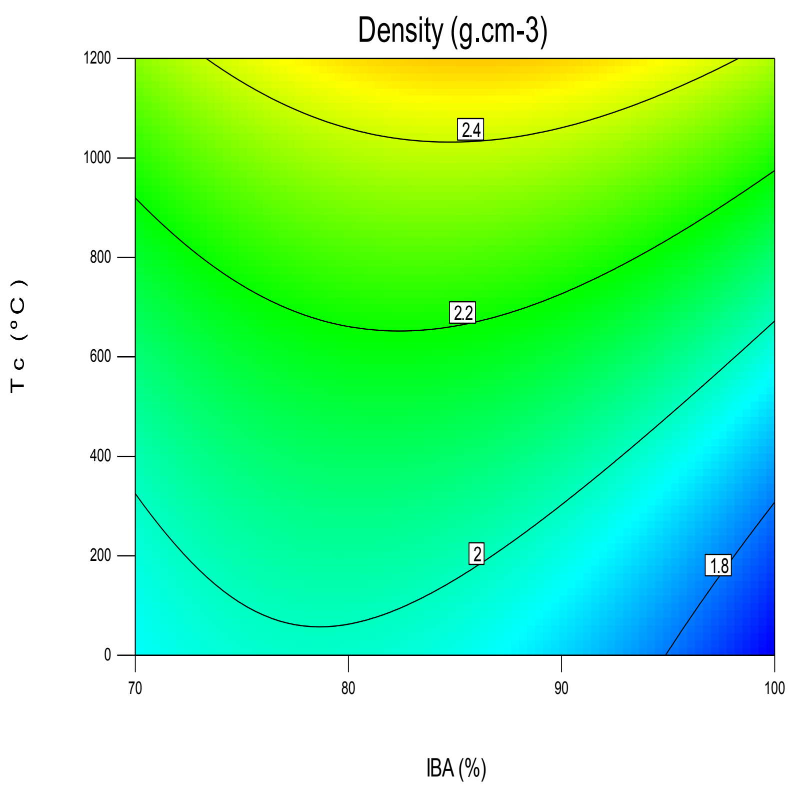


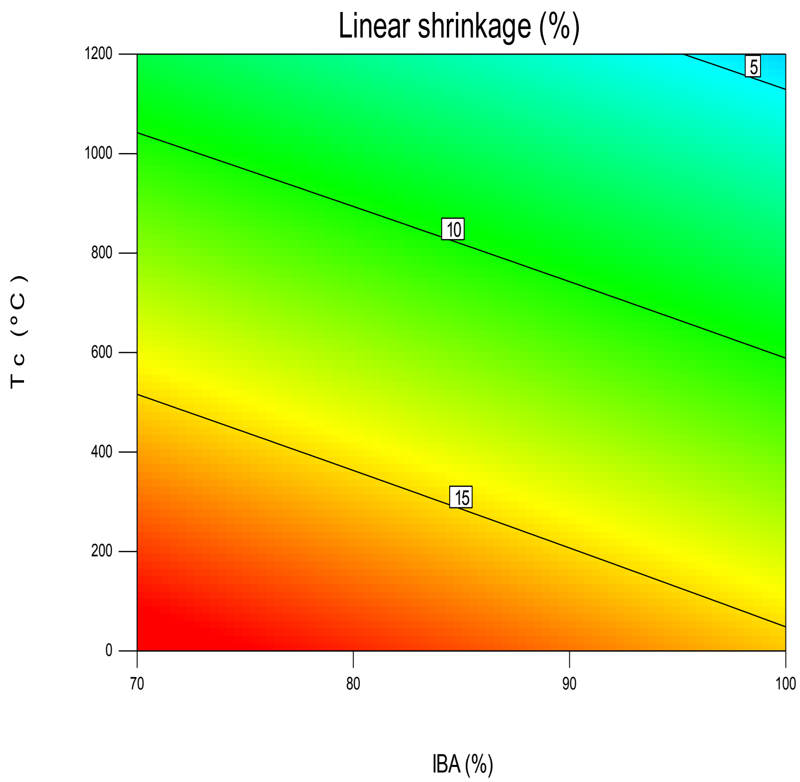
Effect of calcining on density and shrinkage of sintered ceramics

Density

Firing temperature: 1080°C

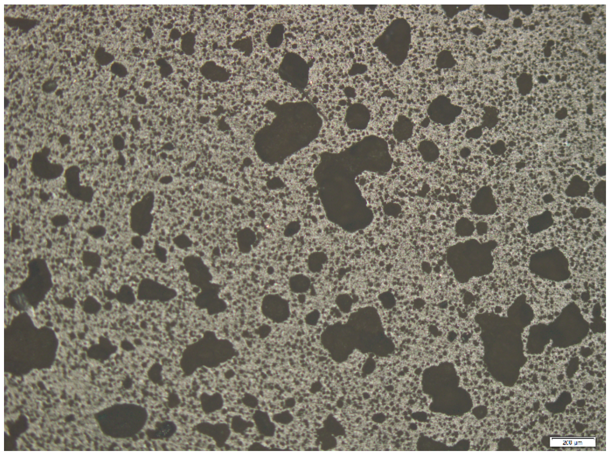
Shrinkage



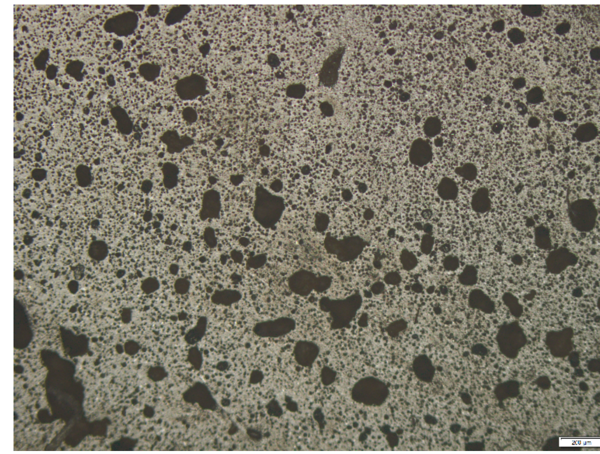


Effect of calcining on microstructure of sintered ceramics

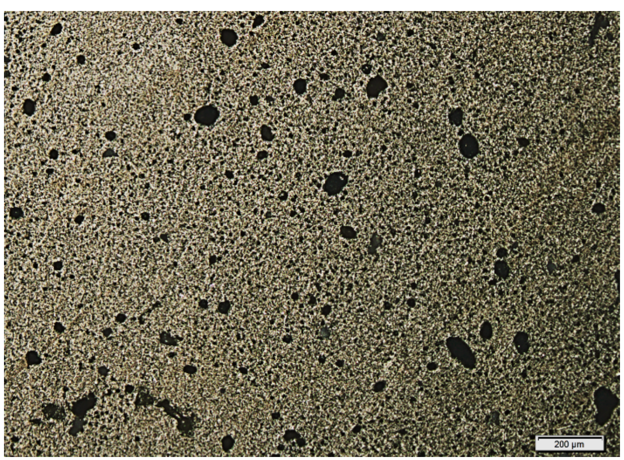
600 °C



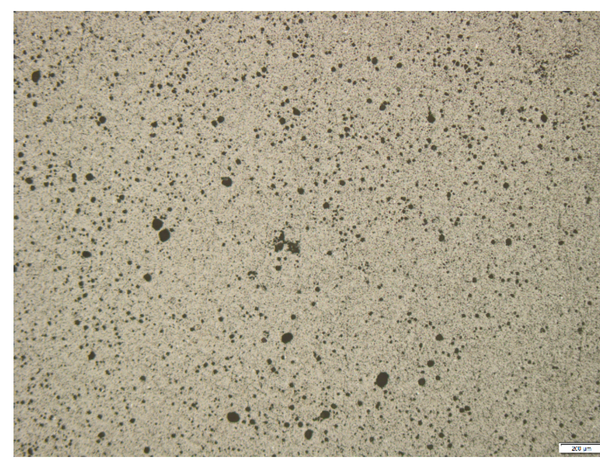
800 °C



1000 °C



1080 °C



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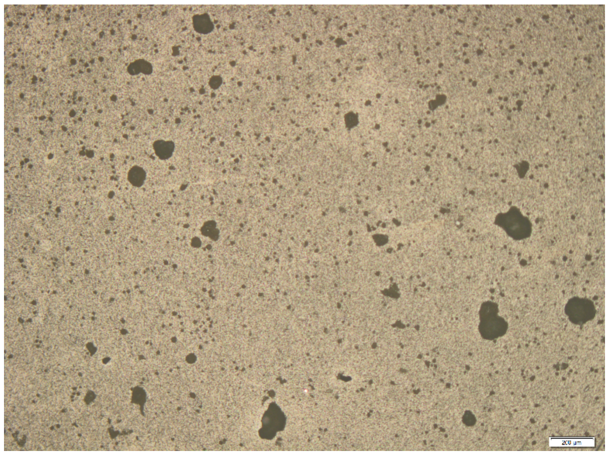
Optimum processing conditions

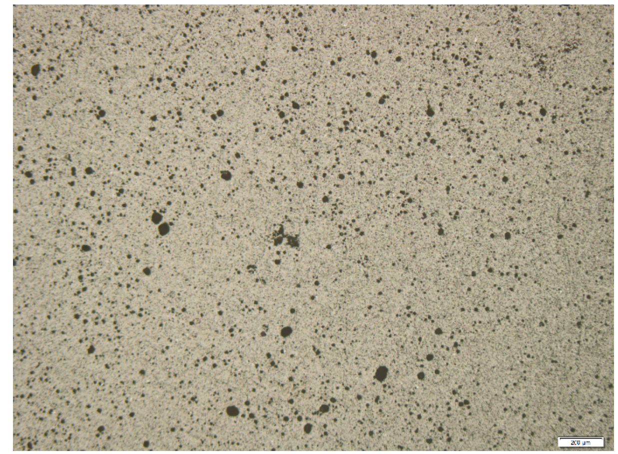
IBA (%)	Tc (°C)	Ts (°C)	Density* (g/cm^3)	Water absorption* (%)	Shrinkage* (%)	Appearance*
100	1200	1130	2.40	0.9	5.1	5.1
90	1100	1100	2.52	0.1	5.3	5.3
80	1080	1080	2.72	0	5.4	5.5
70	1060	1040	2.74	0	5.5	5.3
Clay Ceramics			2.1-2.3	0-5	7-12	

Microstructure of optimum samples

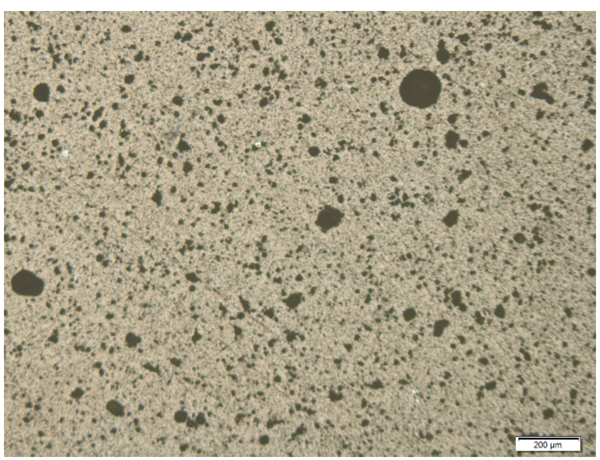
70wt.% IBA



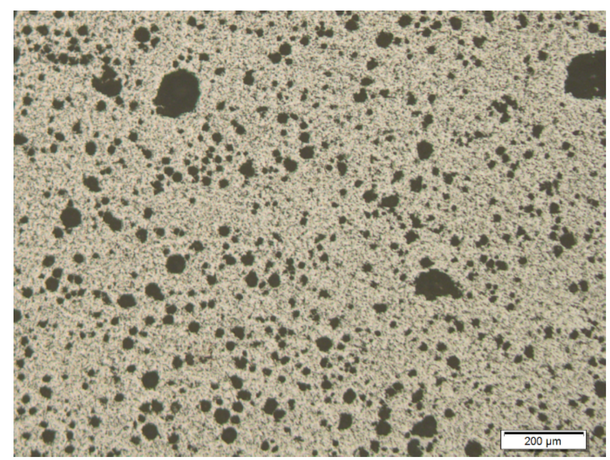
80wt.% IBA



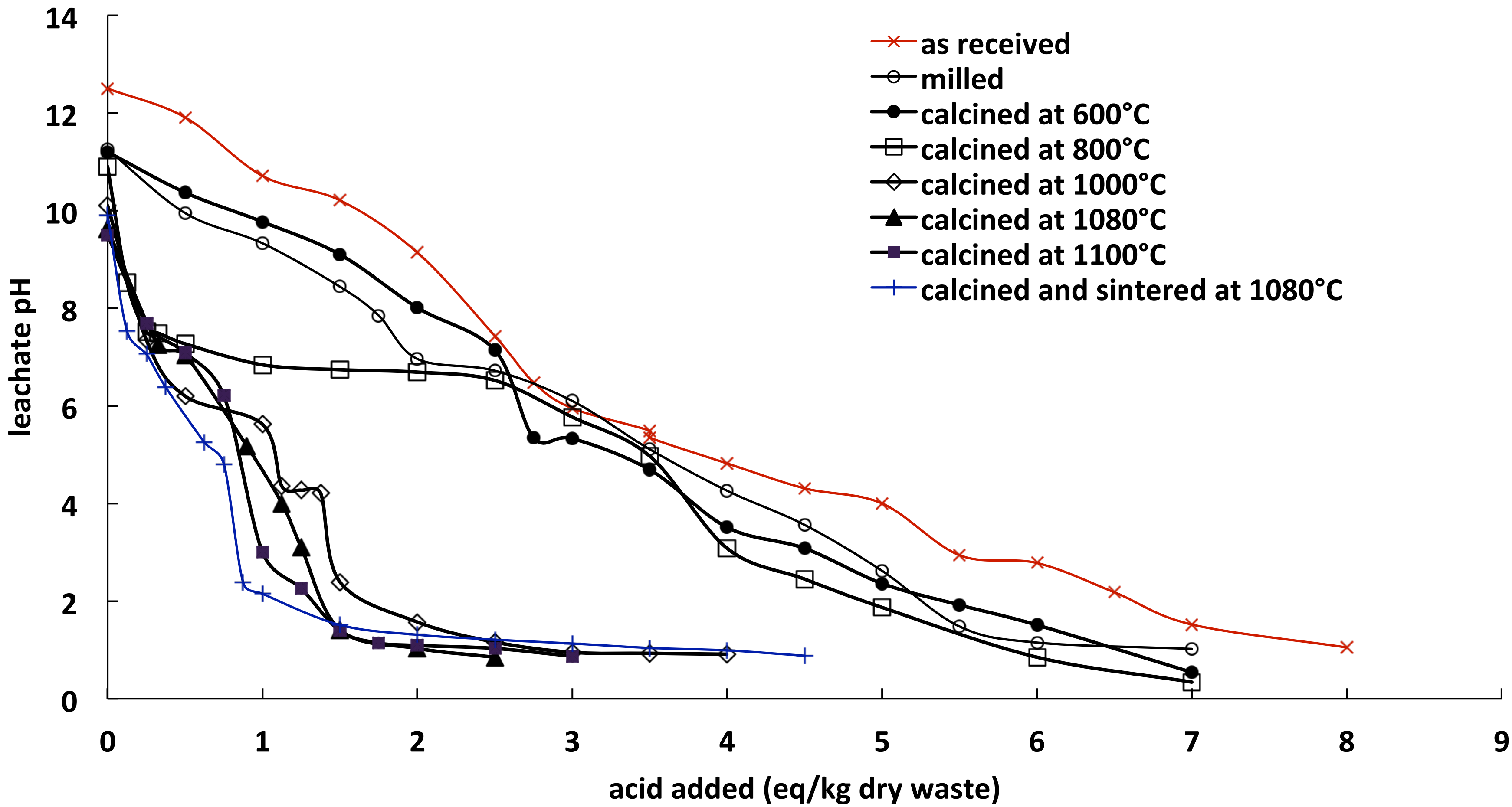
90wt.% IBA



100wt.% IBA



Effect of calcining on Acid Neutralisation Capacity



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Metals: IBA as received, pyroxene powder and sintered ceramic

		Amount leached (leachate pH 3)					
	Concentration in IBA	IBA as received	Pyroxene powder		Sintered ceramic		
	mg/kg	mg/kg	mg/kg	% reduction	mg/kg	% reduction	
Cr	163	17.9	0.75	**95.8**	0.6	**96.7**	
Cu	3200	887.6	21.8	**97.5**	19.5	**97.8**	
Ni	197.5	9.3	0.13	**98.6**	0.05	**99.5**	
Cd	63	4.6	0.16	**96.5**	0.09	**98.1**	
Zn	3100	1139.4	9.4	**99.2**	8.2	**99.3**	
Pb	350	133.1	0.15	**99.9**	0.07	**99.7**	
Al	11500	1742	57.9	**96.7**	53.1	**96.9**	
Fe	4600	1013	6.12	**99.4**	4.5	**99.6**	

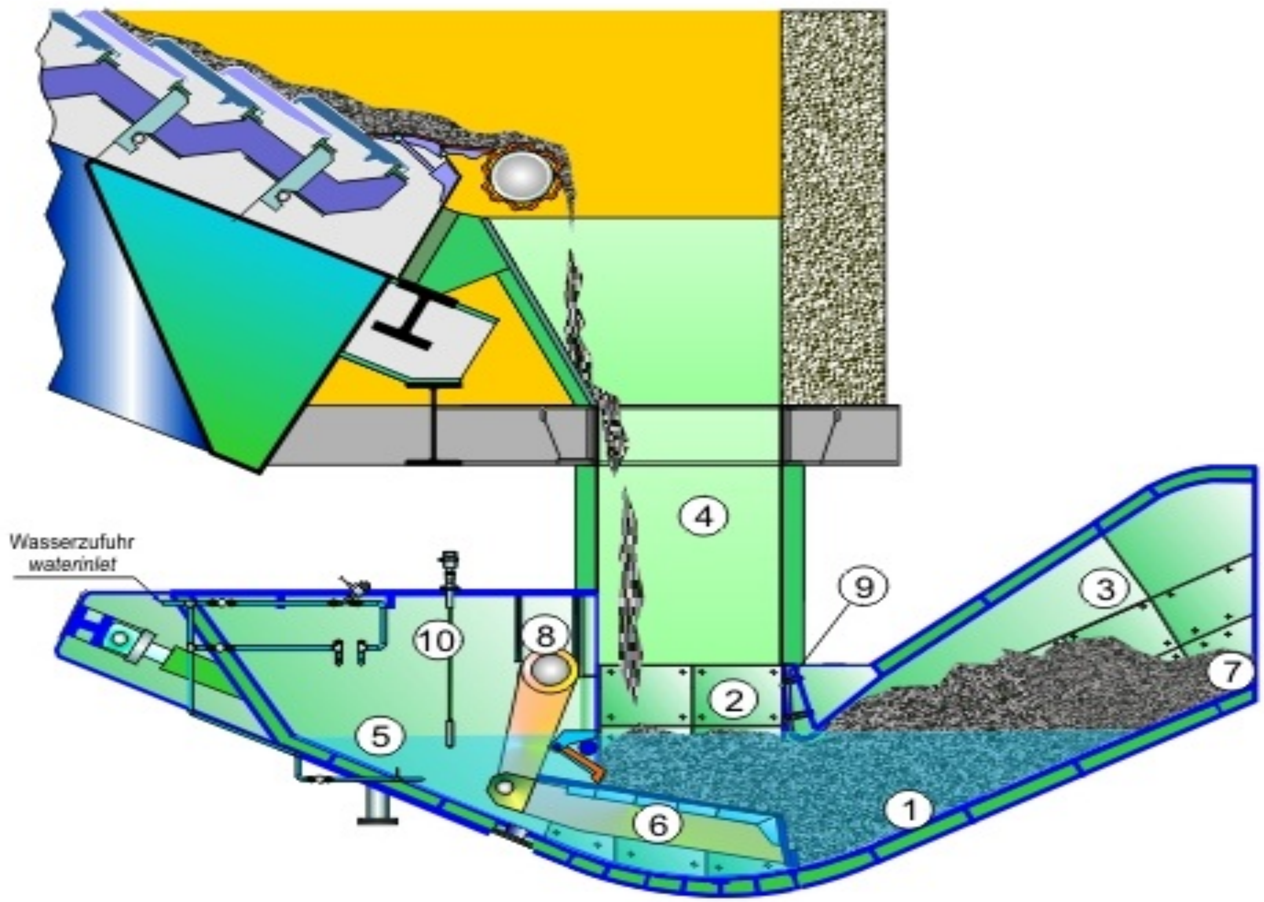
Comparison of mechanical properties of sintered ceramics

Mechanical property	Sintered ceramics	Clay ceramics	Alumina ceramics
Density (g/cm^3)	2.7	2.3	3.8
Young's modulus (GPa)	76.2	71	300
3-point bending strength (MPa)	80.9	78.2	400
Vickers microhardness (GPa)	4.4	3.1	20
Thermal conductivity (W/m*K)	0.6	0.6	3

Sintered ceramic derived from Martins' dry discharged fine IBA

Effect of ash variability: The less than 4 mm wet discharged IBA

Wet discharged IBA: traditional process



1 Discharger tub
2 Inlet section
3 Outlet chute
4 Connecting piece
5 Water level
6 Discharge ram
7 Drop-off edge
8 Drive shaft
9 Air sealing wall
10 Electrically-controlled level metering system

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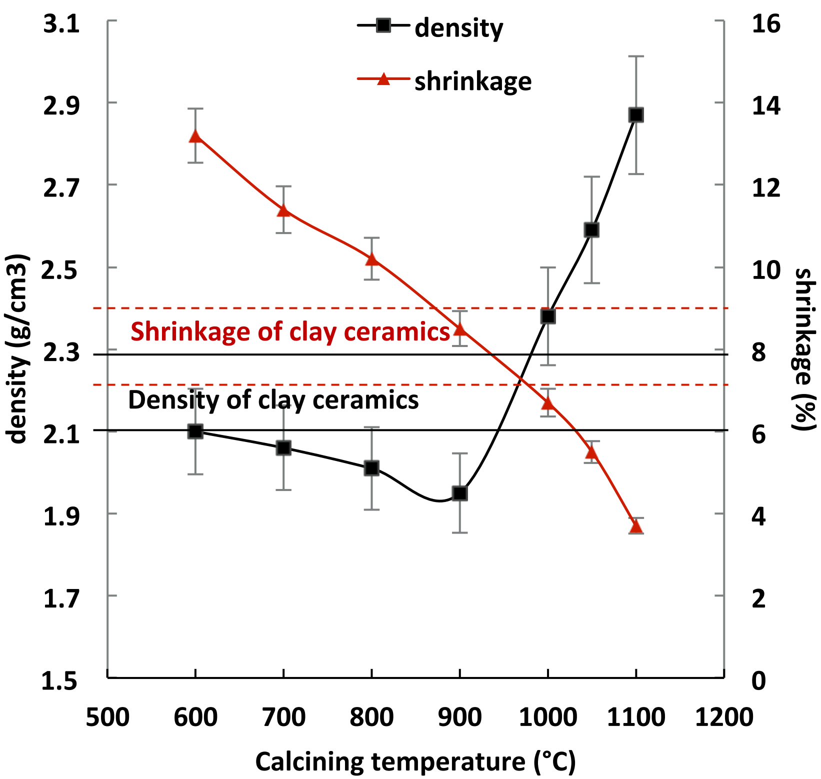
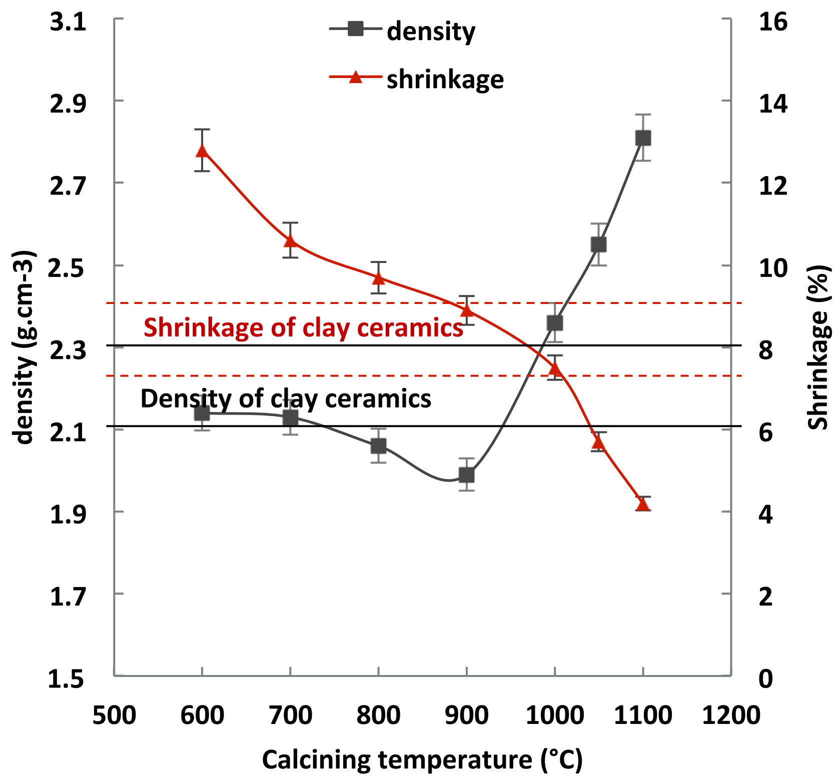
Effect of calcining temperature on density and shrinkage: 80 IBA- 20% glass mix

Wet milling 24 hours
Pressing Pressure:32 Mpa
Firing temperature: 1080°C

Dry discharged sample



Wet discharged sample



Cost of processing

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Cost of processing: IBA quantity

Assumptions:

- IBA is ~25 to 30% by mass of the Municipal Solid Waste (MSW) feedstock
- <500µm dry discharged IBA represents 10wt.% of total IBA
- <4 mm wet discharged IBA represents 40wt.% of total IBA

Dry discharge system:

- Monthey facility produces ~ 10,500 tonnes of less than 500µm IBA per year

Wet discharge system:

- In UK ~500,000 tonnes of less than 4 mm IBA produced per year

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Cost of processing: IBA disposal costs

Switzerland[1]:

Method applied	Haulage ($/ t)	Gate fee ($/ t)	Tax ($/ t)	Cost	
				$/t	$/ yr*
Stabilised in ultimate landfills	5.8	16.8	13	35.6	~ 373,800

United Kingdom[2]:

Method applied	Haulage ($/t)	Gate fee ($/t)	Tax ($/t)	Cost	
				$/t	$/ yr*
Non-hazardous landfills	5.8	48.5	128.3	182.6	~ 91.3 million

* assumption: 100% of the fine IBA is disposed of to landfills
[1] Data from CEWEP report, 2013
[2] Data from WRAP report, 2013

Cost of processing: Estimated lab scale, pilot scale and full scale costs

Scenario I: Ceramic tile production

Operation	Energy consumption[1] (kWh/t fired product)	UK pilot plant operating costs per tonne IBA	Swiss pilot plant operating costs per tonne IBA
Milling	65	$10.6	$10.6
Spray Drying	7	$1.2	$1.2
Calcining	50	$8.2	$8.2
Pressing	14	$2.3	$2.3
Sintering	50	$12.8	$12.8
Landfill saving		$182.6	$35.6
Total[2]	**186**	**- $147.5**	**- $0.5**

[1]Average values from EU BREF document on ceramic industries

[2]Total cost excludes the ceramic tile revenue to be defined by the application to be used. The tile can be used for the infrastructure (i.e. pavements) of the plant, therefore construction savings should be subtracted from the total. For Monthey plant the cost for mixing IBA with fly ash is excluded.

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Cost of processing: Estimated lab scale, pilot scale and full scale costs

Scenario II: Ceramic powder production

Operation	Energy consumption[1] (kWh/t fired product)	UK pilot plant operating costs per tonne IBA	Swiss pilot plant operating costs per tonne IBA
Milling	65	$10.6	$10.6
Spray Drying	7	$1.2	$1.2
Calcining	50	$8.2	$8.2
Landfill saving		$182.6	$35.6
Total[2]	**186**	**- $162.6**	**- $15.6**

[1]Average values from EU BREF document on ceramic industries

[2]Total cost excludes the ceramic powder revenue to be defined from the pyroxene ceramic to be used. For Monthey plant the cost for mixing IBA with fly ash is excluded.

Production of foamed materials containing fine IBA

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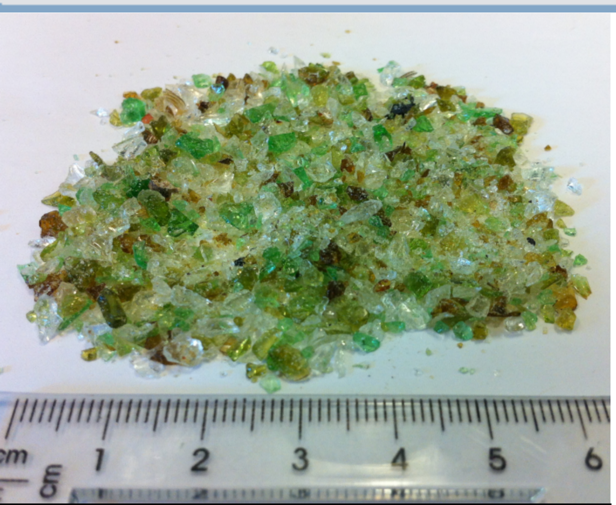
Production of foamed glass containing IBA



Glass

Milled glass

Moulded sample

Sintered samples post tumbling

Sintered samples

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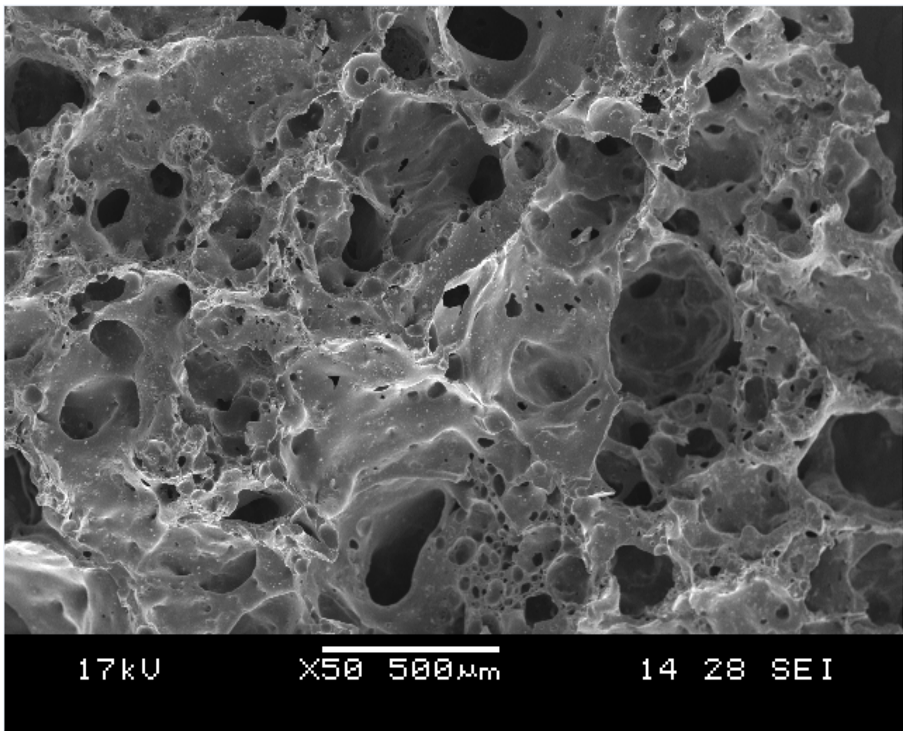
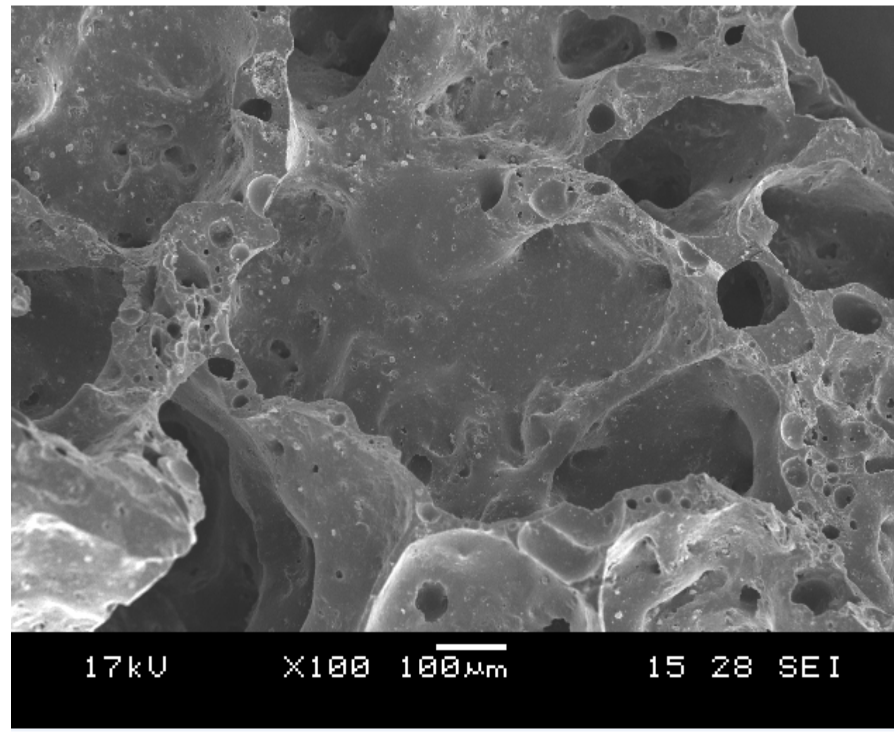
Effect of rapid sintering: SEM images of foamed materials containing IBA





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Conclusions

- Particle size, sintering and calcining temperature control properties and microstructure;
- Calcining at 1080°C produces:

  Ceramics which have improved properties than commercial ceramic tiles

  Different crystalline phases

- Calcining reduces the ANC and the leaching of metals compared to the as received fine IBA;
- Potential to manufacture powders suitable for ceramic production;
- Control of processing allows production of;

  Dense monolithic ceramics

  New lightweight foamed materials

Waste to Energy providing new material resources

Thank you very much for your attention!

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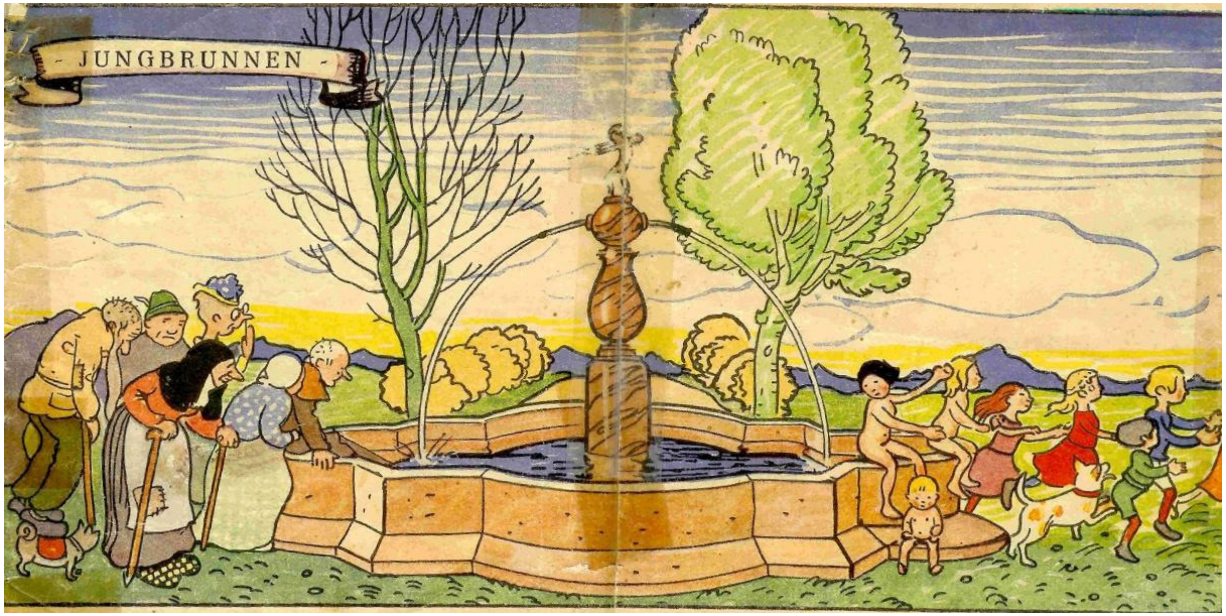

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Wheelabrator Technologies Inc.
A Waste Management Company

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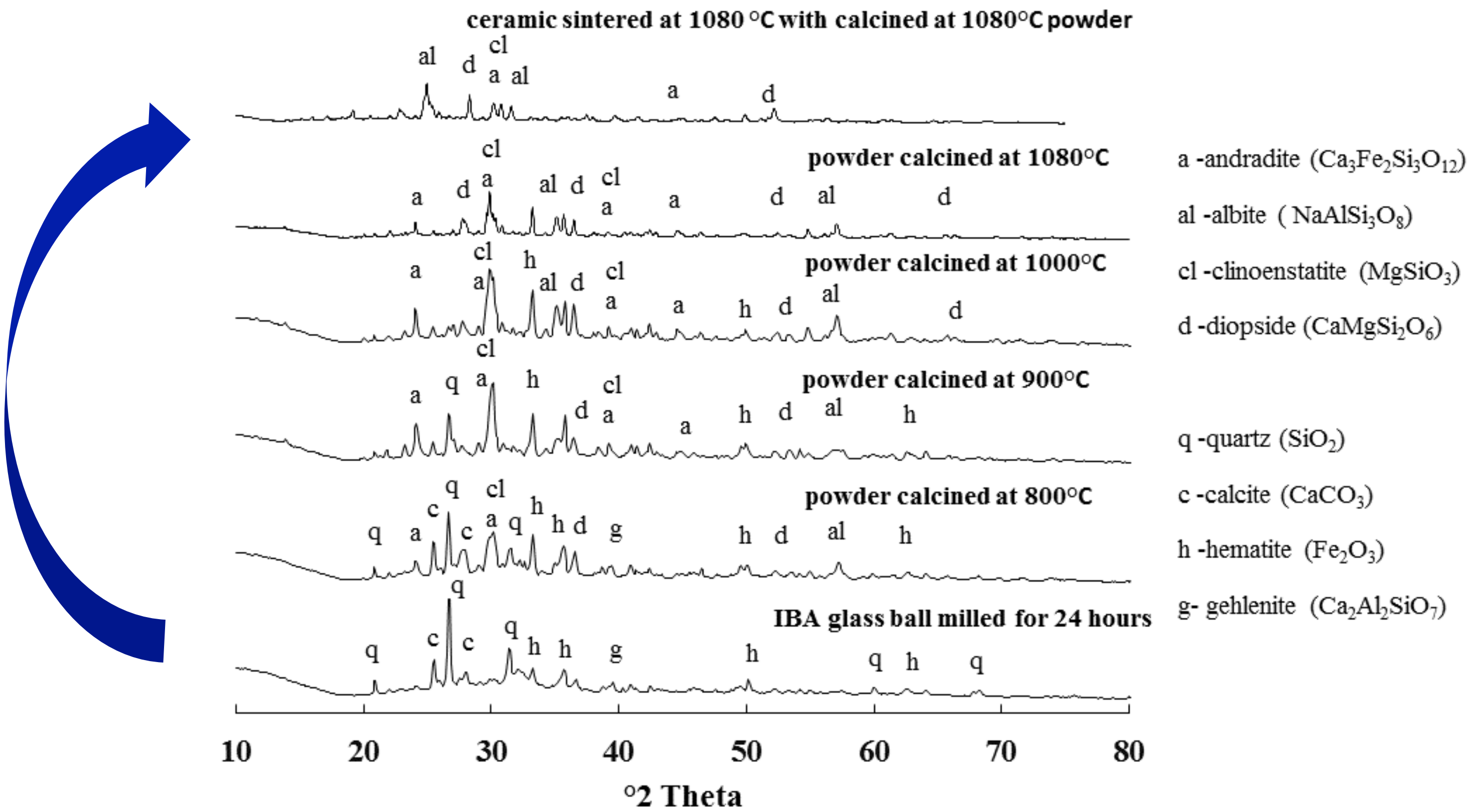
XRD during calcining: wet discharged IBA



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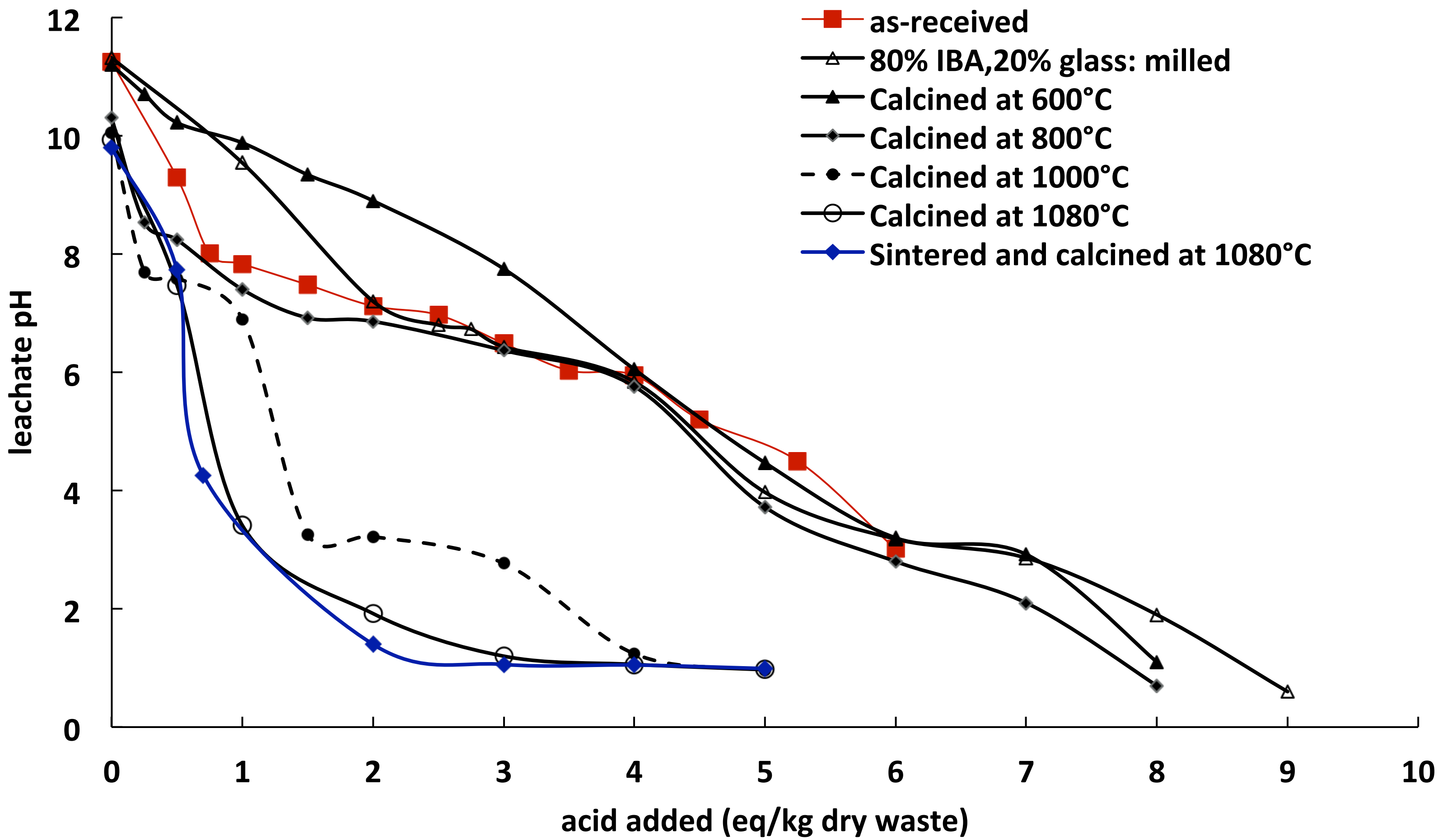
Acid Neutralisation Capacity during calcining: Fine IBA from wet discharge process



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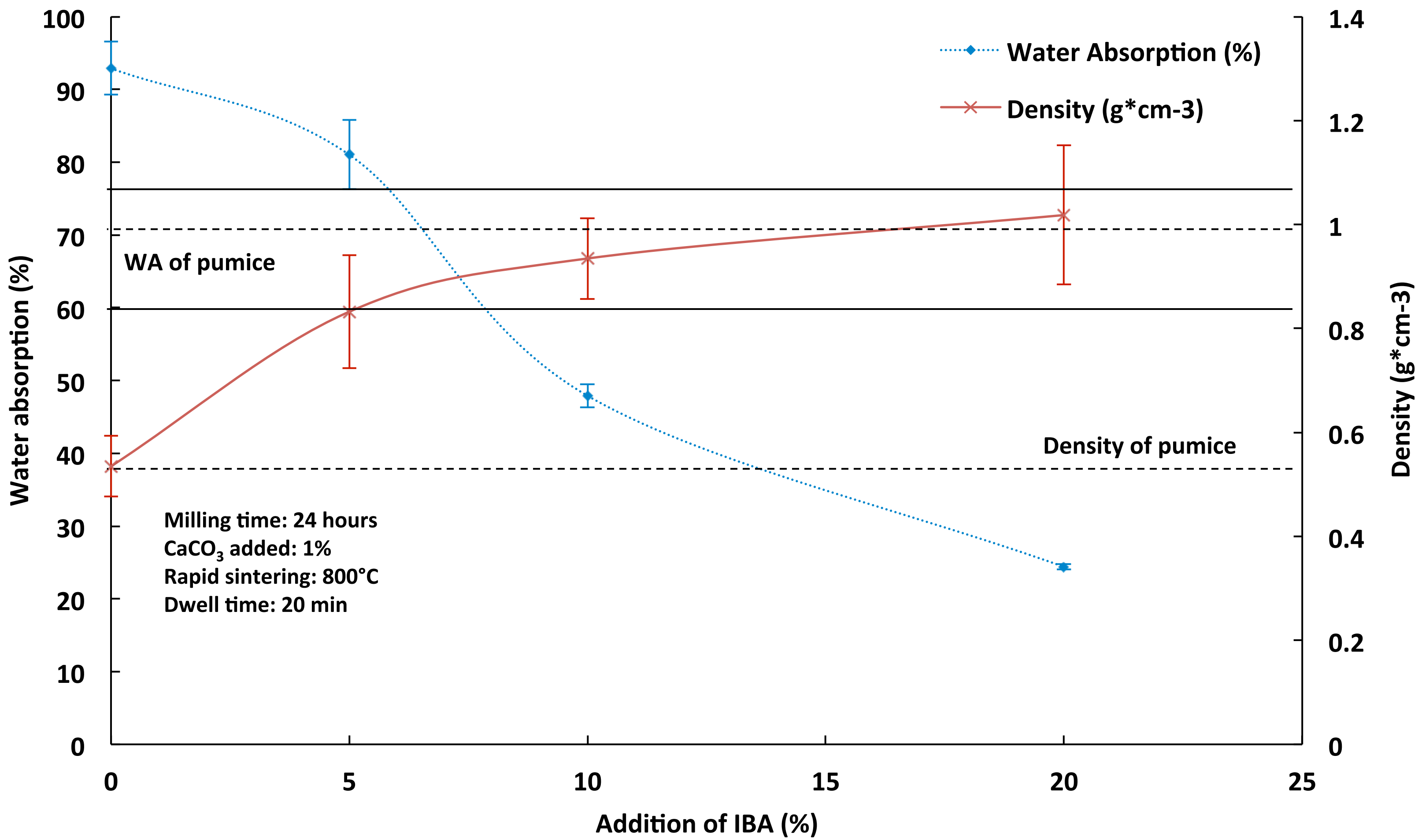
Effect of rapid sintering: production of foamed materials



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Acid Neutralisation Capacity