Foamed Geopolymer Made by Additive Manufacturing for the Construction Technology Applications (3D-FOAM)

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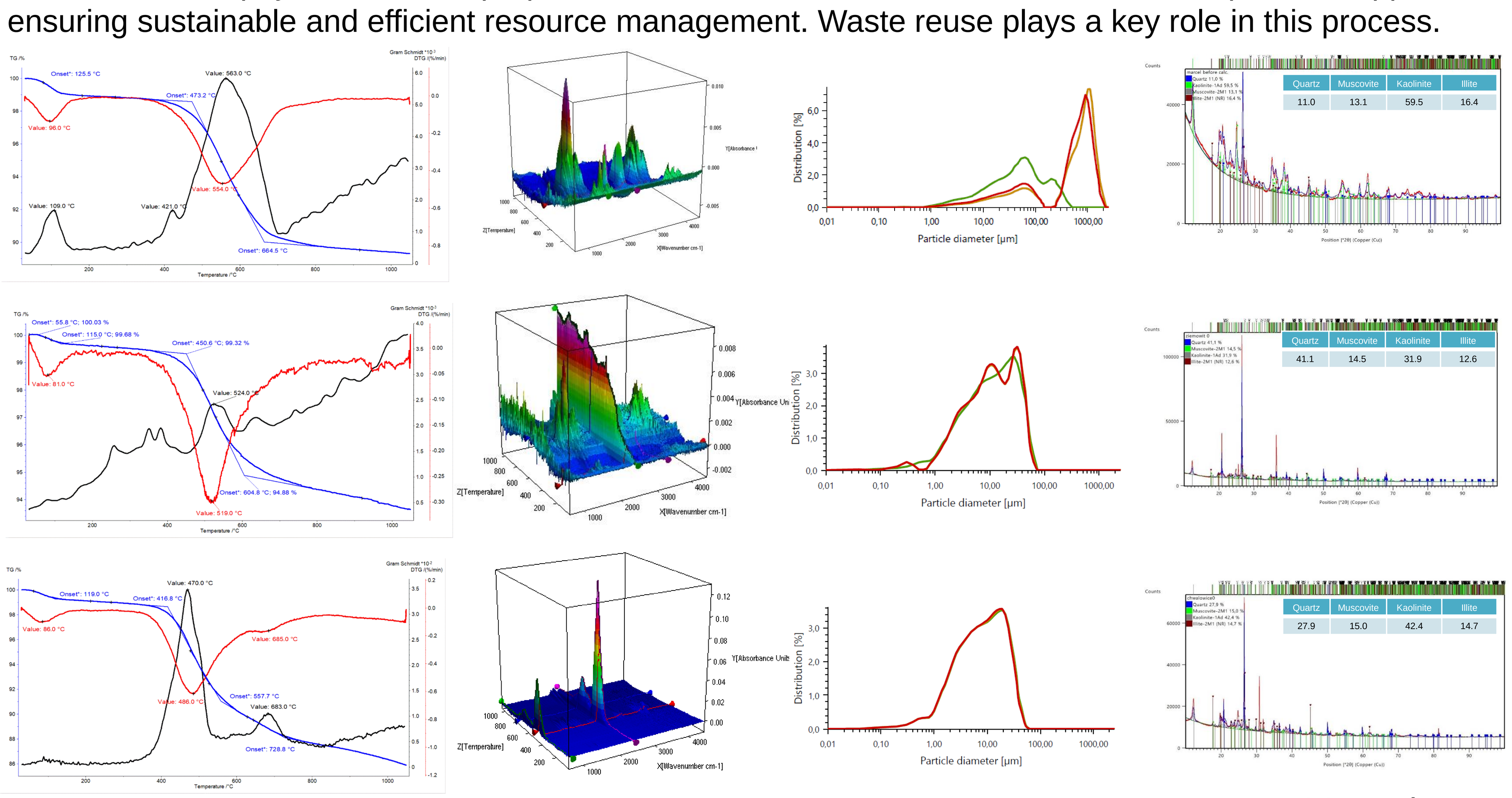
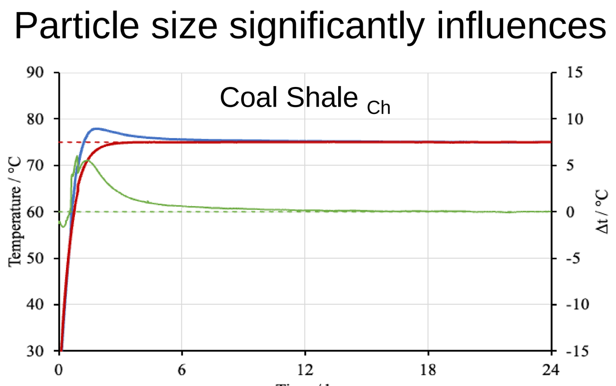
Additive manufacturing (AM) is a rapidly evolving industrial sector and a potentially disruptive technology. It offers new possibilities for the construction industry, particularly in terms of geometrical flexibility, reduction of labor costs, improved efficiency and safety, suitability for harsh environments, and sustainability. This project addresses emerging challenges in AM, such as resource efficiency, energy savings, and sustainability, which are critical compared to conventional construction methods. Despite the successful implementation of 3D printing in industries such as aerospace and automotive, its application in concrete construction remains in its early stages. The full exploitation of 3D AM processes is currently limited by the performance of available material sets, both during processing and in-service conditions. To meet market and societal demands, particularly in the context of circular economy principles, this research focuses on developing zero-waste 3D printing technology by utilizing waste materials such as crushed clay bricks, aerated concrete, and disintegrated cement as raw materials. The primary objective was to engineer foamed ceramic materials tailored for additive manufacturing, specifically geopolymer composites (GP) and hybrid geopolymer composites (HGP) with optimized properties for construction applications. The research involved: Preliminary assessment of the physicomechanical properties of raw materials; development of long-term performance characteristics of printed structures; evaluation of durability, fire resistance, and thermal properties; optimization of processing techniques to enhance sustainability. The developed materials exhibit: controlled porous structure; low density; high thermal resistance and low thermal conductivity; satisfactory mechanical properties; excellent fire and heat resistance; eco-friendliness; and cost-effectiveness. This novel class of materials is designed for use as thermal insulators while maintaining non-flammable properties, making them particularly attractive for the construction sector. Lightweight materials with superior thermal performance have the potential to revolutionize sustainable building technologies.

Validation of the physicochemical properties of construction materials is crucial for their practical application, ensuring sustainable and efficient resource management. Waste reuse plays a key role in this process.

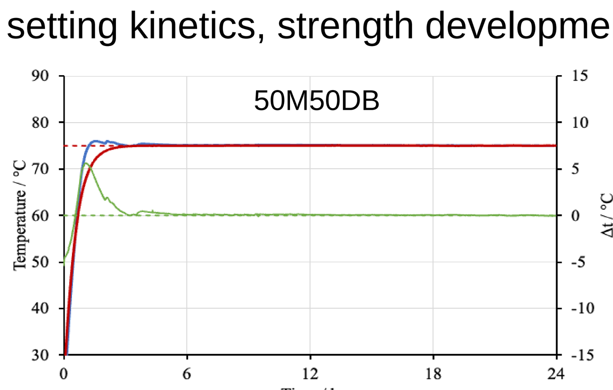


TG-FTIR analysis results of raw materials — Particle size analysis — XRD results

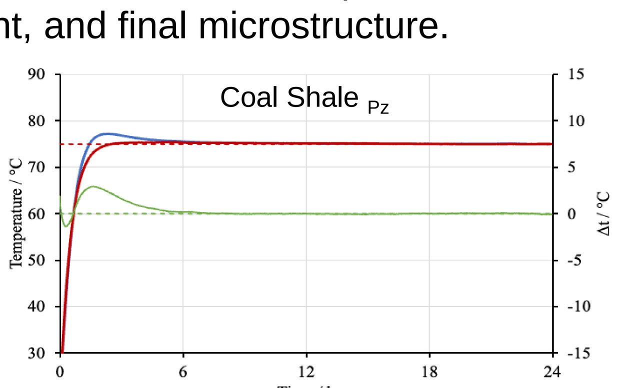
One of the critical factors in using 3D-printed concrete, geopolymers, and ceramic composites is the setting time of individual layers. Traditional hydration analysis methods for cementitious materials are insufficient. A thermistor-based method enabled the identification of the heat release phenomenon. Particle size significantly influences setting kinetics, strength development, and final microstructure.



Start of setting time [h]	End of setting time [h]	Exothermic reaction [J/m*K]
0:32:12	20:05:28	1.79

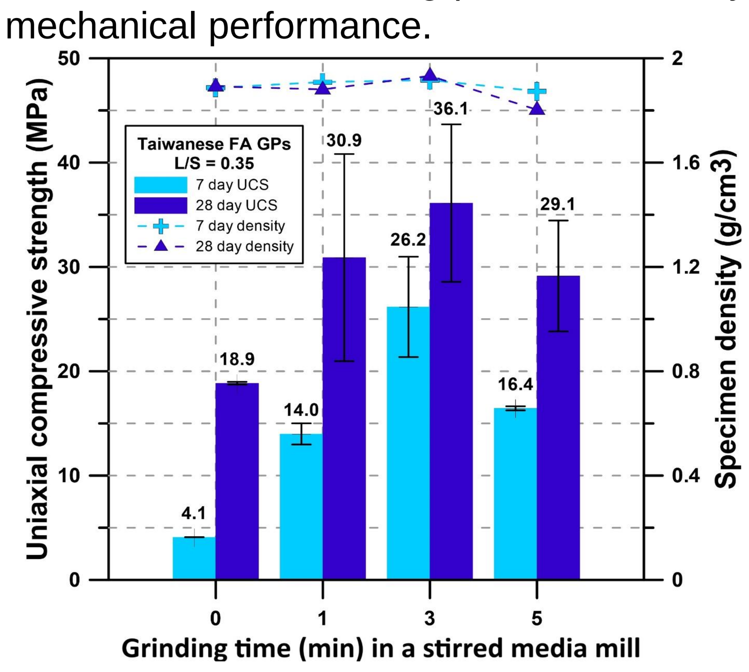


Start of setting time [h]	End of setting time [h]	Exothermic reaction [J/m*K]
0:33:42	03:11:21	0.59

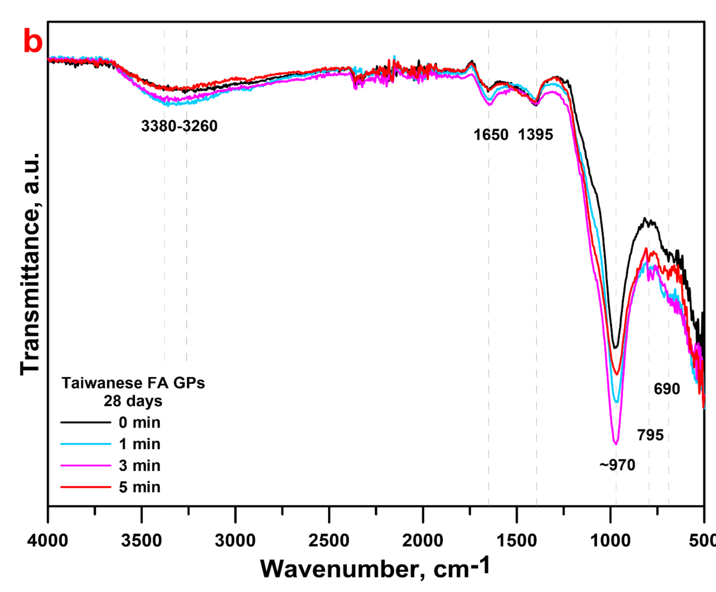


Start of setting time [h]	End of setting time [h]	Exothermic reaction [J/m*K]
0:23:58	07:38:48	0.64

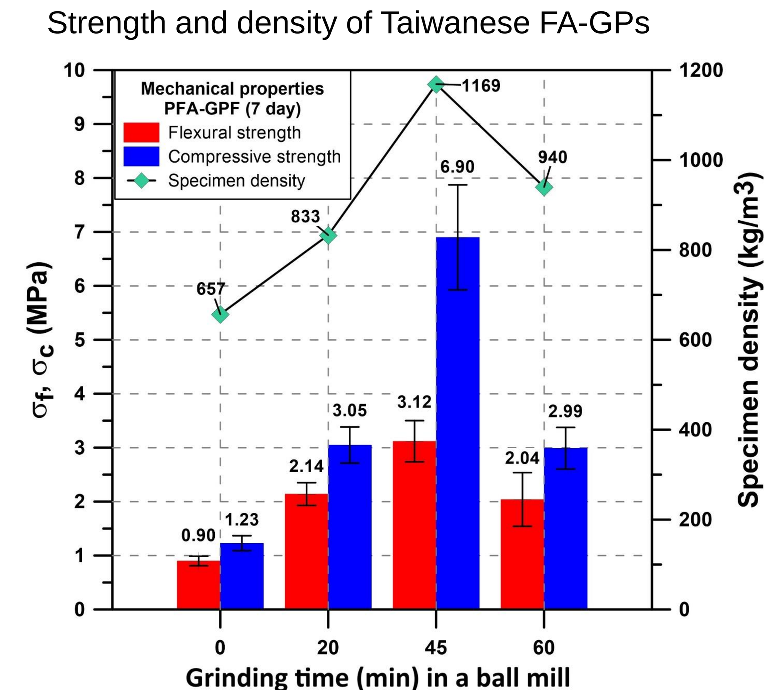
Mechanical activation, achieved through particle size reduction, increased specific surface area, and amorphization, enhances the reactivity of raw materials, thereby improving the mechanical properties of geopolymers (GPs) and geopolymer foams (GPFs). Additionally, it influences the rheological behavior of the paste, which plays a crucial role in the development of the pore structure in GPFs. Excessively high paste viscosity inhibits pore formation, leading to a reduced pore size, whereas excessively low viscosity facilitates the escape of gas generated by the foaming agent, resulting in a denser structure. Furthermore, mechanical activation accelerates chemical reactions, which affects the foaming process and may lead to the formation of GPFs with reduced mechanical performance.



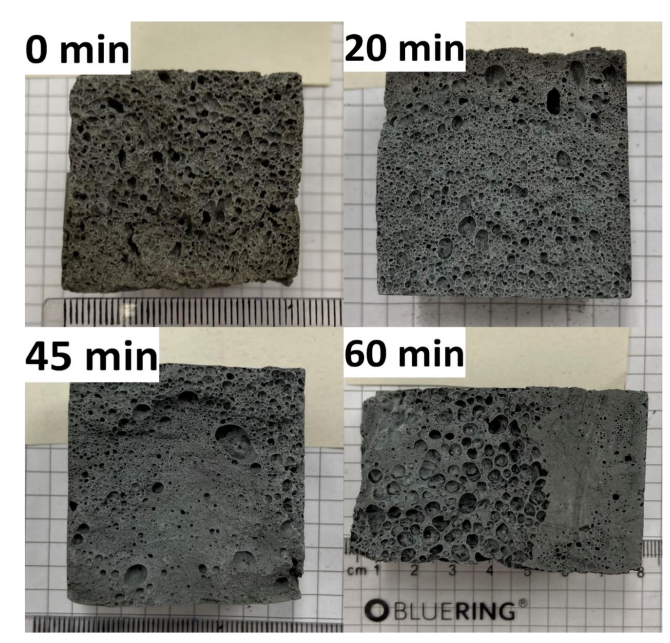
Strength and density of Taiwanese FA-GPs



FTIR spectra of Taiwanese FA-GPs



Strength and density of Polish FA-GPFs



Pore structure of Polish FA-GPs

Cementless foam materials have been developed to fulfill the requirements for sustainable construction. These materials utilize binders derived from locally sourced industrial by-products, which, in combination with hydrogen peroxide and additional foaming agents such as sodium lauryl sulfate and polyvinyl alcohol, enable the production of printable foamed materials.

Cementless Foam Materials with hydrogen peroxide

- Binders: FA+RUFA+GGBS
- Compressive Strength: 0.2~3.7 MPa
- Density: 634~830 kg/m³
- Thermal Conductivity: 0.08~0.11 W/mK
- Optimum foaming agent: 5%H_2O_2

Cementless Foam Materials with Sodium Lauryl Sulphate and Polyvinyl Alcohol

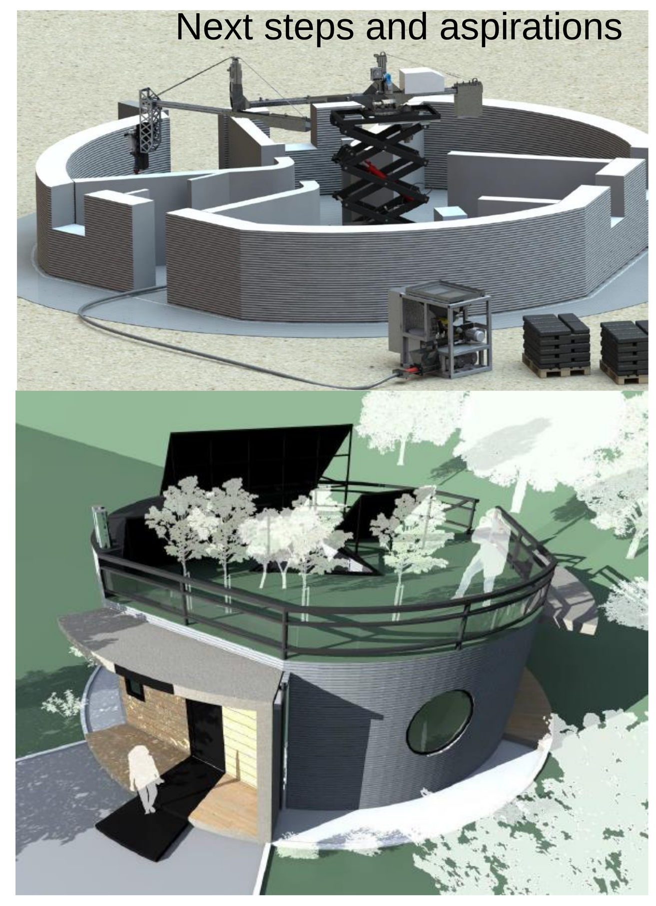
- Binders: RUFA+CFA
- Compressive Strength: 0.9~4.0 MPa
- Density: 880~1150 kg/m³
- Thermal Conductivity: 0.09~0.14 W/mK
- Optimum foaming agent: 2%SLS+0.4%PVA

R70C30 R80C20

Foam Geopolymer with Hydrogen Peroxide

- Binders: Fly ash (activator→NaOH+Na_2SiO_3)
- Compressive Strength: 1.5~2.0 MPa
- Density: 600~650 kg/m³ (using SLS as the stabilizer)
- Thermal Conductivity: 0.08~0.09 W/mK
- Optimum foaming agent: 1.5%SLS or PVA+5%H_2O_2

Next steps and aspirations



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