Preliminary Fresh-State Assessment of a Geopolymer Matrix for RLOW Simulant Conditioning within the EURAD-2 Project

Francesco Rizzo[1], Giacomo Marta[1], Fabio Giannetti[1], Luca Di Palma[2], Francesca Limosani[3], Tiziana Guarcini[3], Maria L. Cozzella[3], Fabio Girardi[3], Danilo Casagrande[3], Riccardo Levizzari[4], Gianfranco Caruso[1]

1 Sapienza University of Rome, Department of Electrical and Energy Engineering (DIEE)
2 Sapienza University of Rome, Department of Chemical Engineering Materials Environment (DICMA)
3 ENEA, NUC-IRAD-CRGR, Nuclear Material Characterization Laboratory and Nuclear Waste Management
4 ENEA, NUC-IRAD

**fr.rizzo@uniroma1.it*

Introduction

Addressing the critical challenge of safe nuclear waste management, this study investigates the fresh-state behaviour of a ternary geopolymeric binder composed of fly ash (FA), metakaolin (MK), and ground granulated blast-furnace slag (GGBS), activated with a potassium hydroxide/potassium silicate (KOH/K_2SiO_3) solution. This research was carried out within WP7 L'OPERA of the European Joint Programme EURAD-2. The geopolymeric formulation, referred to as KIPT from the PREDIS project, develops a nanostructured aluminosilicate network typical of alkali-activated ternary systems, providing the physical and chemical framework for waste immobilization. The KIPT binder was tested with increasing contents of waste motor oil (0, 10, 15, and 20 wt.%) as a simulant for radioactive liquid organic waste (RLOW), assessing the feasibility of immobilizing such waste streams within an alkali-activated matrix. Workability and rheological behaviour were evaluated through mini-slump tests, while setting kinetics were monitored using the Vicat needle method. Differential scanning calorimetry (DSC) on fresh specimens was employed to investigate the thermal response and exothermic reactions associated with the early stages of geopolymerization. These preliminary results provide insight into how the RLOW simulant affects the fresh-state properties and setting behaviour of the KIPT system, offering a basis for identifying the optimal processing window and the maximum incorporable waste fraction. Combined with future hardened-state characterization, this fresh-state assessment represents a first and necessary step toward evaluating the suitability of the KIPT binder for RLOW conditioning applications.

Materials

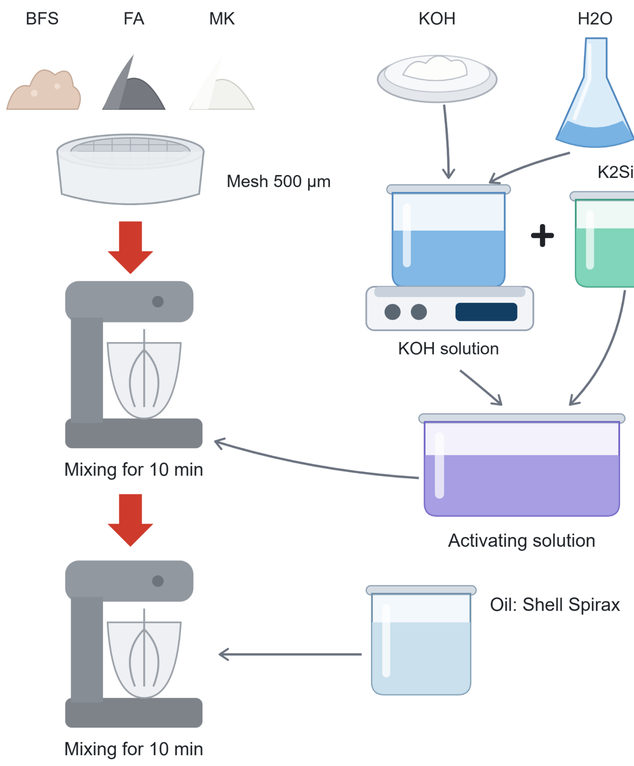
Matrix Composition (KIPT Formulation)

Component	wt.%
Metakaolin (MK)	9.9
Ground granulated blast-furnace slag (GGBS)	18.7
Fly ash (FA)	24.1
Liquid glass (K_2SiO_3)	10.9
KOH	5.9
Water (H_2O)	11.0

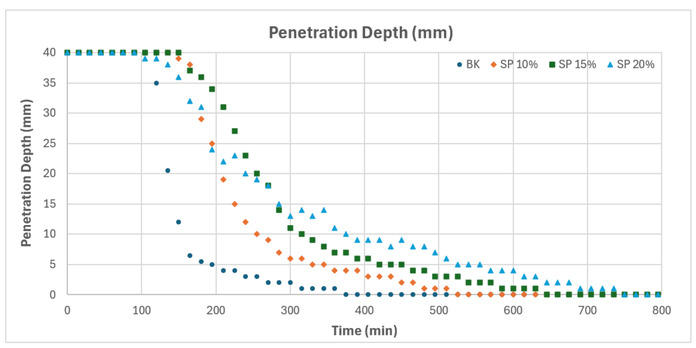
SP (Shell Spirax) Loading by Sample

Sample	Waste load (wt.%)
BK	0
SP 10	10
SP 15	15
SP 20	20

Mixing Process

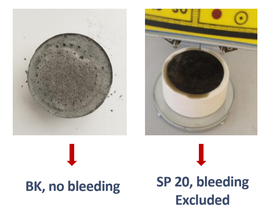


Setting Time Evaluation



For the setting time test (Vicat Needle, ASTM C191-21), the four mixes were prepared and poured into the Vicat apparatus mould. SP addition showed a significant retarding effect on reaction kinetics. SP 20% exhibited pronounced bleeding and non-uniform setting behaviour, and was therefore excluded from further testing.

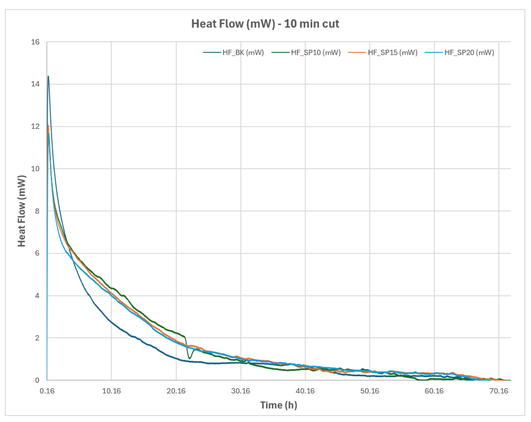
Sample	Initial Setting Time (min)	Final Setting Time (min)
BK	130.3	375.0
SP 10	195.0	525.0
SP 15	232.5	645.0
SP 20	192.9	750.0

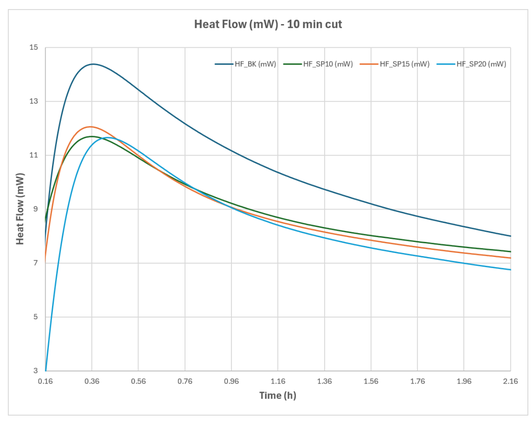


Heat Flow Rate Measurement

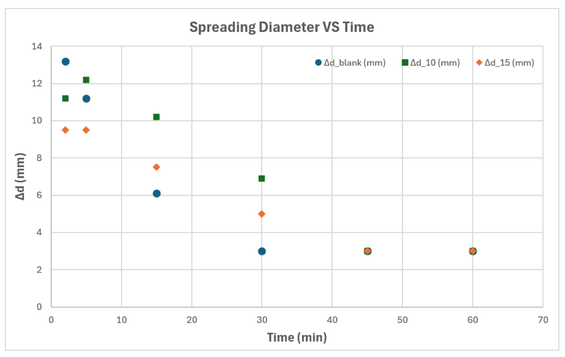
Heat Flow measurements were performed via DSC in isothermal mode at 25°C over 72 hours. After thermalization (first 10 min), BK shown the highest thermal peak (~14.5 mW), decaying rapidly. As SP content increases, the peak slightly decreases and thermal release extends over a longer period.

Sample	Matrix (g)	Shell Spirax (g)	Total Mass (g)
BK	4.50	0.00	4.50
SP 10	4.50	0.45	4.95
SP 15	4.50	0.68	5.18
SP 20	4.50	0.90	5.40

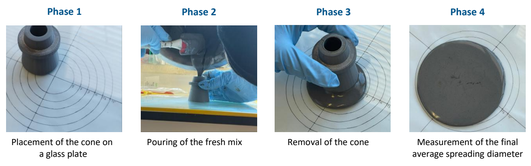




Mini-Slump Test



Time (min)	Δd_blank (mm)	Δd_10 (mm)	Δd_15 (mm)
2	13.2	11.2	9.5
5	11.2	12.2	9.5
15	6.1	10.2	7.5
30	3.0	6.9	5.0
45	3.0	3.0	3.0
60	3.0	3.0	3.0



For the mini-slump test, a scaled-down Abrams cone (bottom Ø 4 cm, top Ø 2 cm, height 6 cm) was used to measure spreading diameter at 2, 5, 15, 30, 45, and 60 minutes for BK, SP10 and SP15. BK shows the highest initial spread with the fastest decay, SP10 retains higher workability at intermediate times, while SP15 decays more gradually.

Discussion and Conclusion

Increasing SP content progressively delayed setting time from 0% (BK) to 15% wt. (SP15), while the 20 wt.% formulation (SP20) showed pronounced bleeding and non-uniform setting behaviour. DSC analysis showed that BK exhibited the highest thermal peak, which decayed rapidly, while increasing SP content slightly reduced the peak intensity and spread the thermal release over a longer period (reaction rate reduction). Mini-slump tests showed BK with a higher initial spread that decayed faster (high reaction rate), SP10 retained an intermediate workability, while SP15 decayed more gradually. Addition of SP reduces the reaction rate (the geopolymerization) and increases the workability. These preliminary fresh-state results provide insight into how the RLOW simulant affects the fresh-state behaviour of the KIPT system, offering a basis for identifying the optimal processing window and the maximum incorporable waste fraction.

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For more information