Characteristics of PZT/Alkali-Activated Composites for Piezoelectric Sensors

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ABSTRACT

This study developed a piezoelectric composite material composed of lead zirconate titanate (PZT) and alkali-activated material (AAM) to investigate the effects of AAM composition and alkali equivalent (N) on dielectric and piezoelectric properties. Green bodies containing 50 vol.% PZT were fabricated under high pressure at 80 MPa, followed by precise infiltration with 0.2 mL of alkali activator. A 1.5 kV/mm electric field was applied to PZT/AAM composites for polarization after 12 hours of curing. Results indicate that the dielectric loss (D) of the GGBS system (100% slag binder) before polarization decreased significantly with increasing alkali equivalent, whereas the opposite trend was found in the fly ash-slag system. The dielectric and piezoelectric properties of all PZT/AAM composites increase with age after polarization, reaching a plateau value after 20 days. The alkali equivalent has a greater effect on the relative permittivity (ε_r) of the fly ash-slag system than the GGBS system does. The binder ratio of fly ash to slag affects the piezoelectric strain constant (d_{33}) of PZT/AAM composite material. At an alkali equivalent of 11%, the d_{33} value reaches 37 pC/N. The piezoelectric voltage factor (g_{33}) values of PZT/AAM piezoelectric elements are all higher than those of piezoelectric ceramic sensors containing 100% PZT, indicating that PZT/AAM composites can be used as piezoelectric sensing elements for structural health monitoring.

BACKGROUND

- **Advancements in piezoelectric cement (PEC)**
  - ✓ PEC was developed for structural health monitoring (SHM) of concrete structures.
  - ✓ PEC aims to eliminate the mismatch between sensors and concrete structures.
- **Potential of Alkali-Activated Materials (AAM)**
  - ✓ AAM offers lower carbon emissions over cement binders.
  - ✓ AAM has a higher ionic conductivity than cement binders.

MIXTURE PROPORTION

PZT/AAM sensors are composed of 50 vol.% AAM matrix and 50 vol.% PZT particle inclusion.

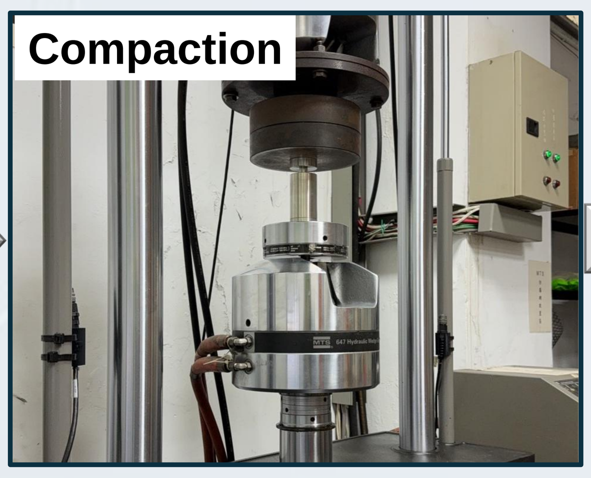
AAM matrix	GGBS (wt.%)	FA (wt.%)	N* (wt.%)
SL100F0N5	100	0	5
SL100F0N7	100	0	7
SL100F0N9	100	0	9
SL100F0N11	100	0	11
SL75F25N7	75	25	7
SL75F25N9	75	25	9
SL75F25N11	75	25	11

* N: alkali equivalent

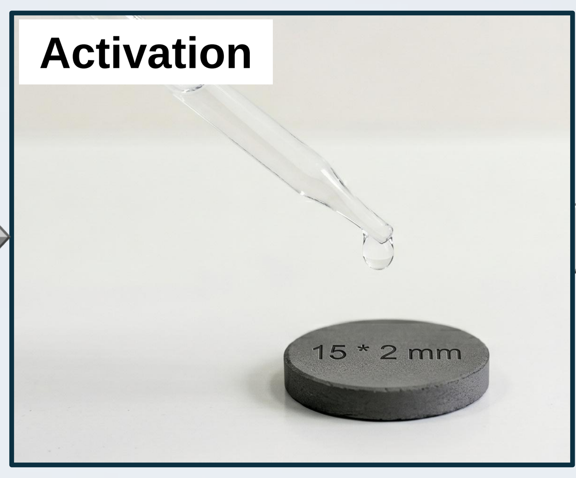
MANUFACTURING OF PZT/AAM SENSORS

Mixing

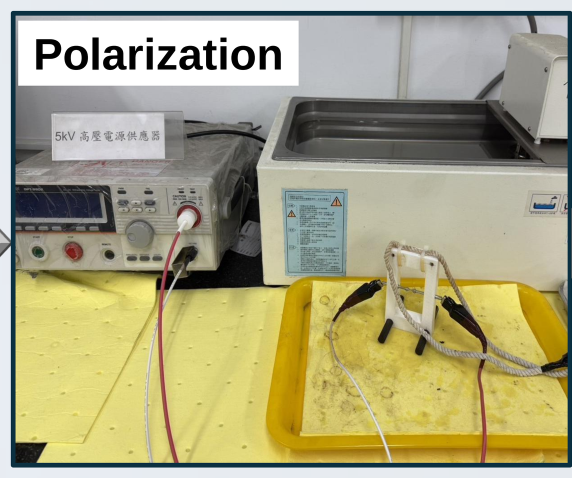
Compaction



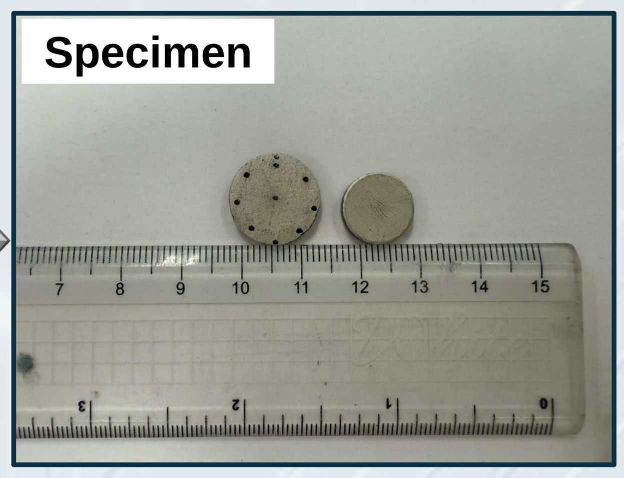
Activation



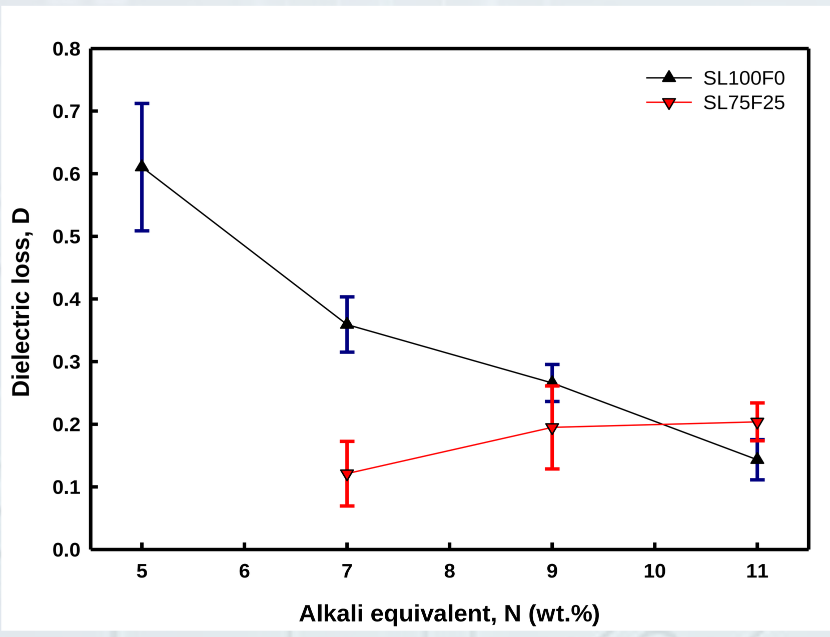
Polarization



Specimen



RESULTS



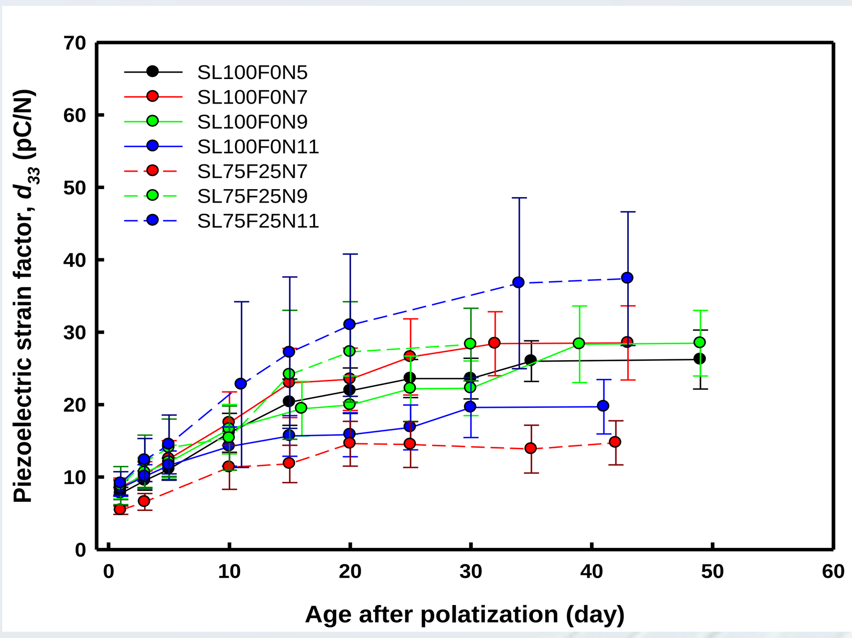
▲ Dielectric loss

- **GGBS systems:**

Higher alkali equivalent (N= 5% to 11%) accelerates early hydration, forming a dense microstructure, immobilizing free ions, and reducing dielectric loss **from 0.61 to 0.14.**

- **FA-GGBS systems:**

The D value of PZT/AAM sensors containing fly ash increases with increasing alkali equivalent. The D value reaches a minimum of **0.12 at N = 7%.**



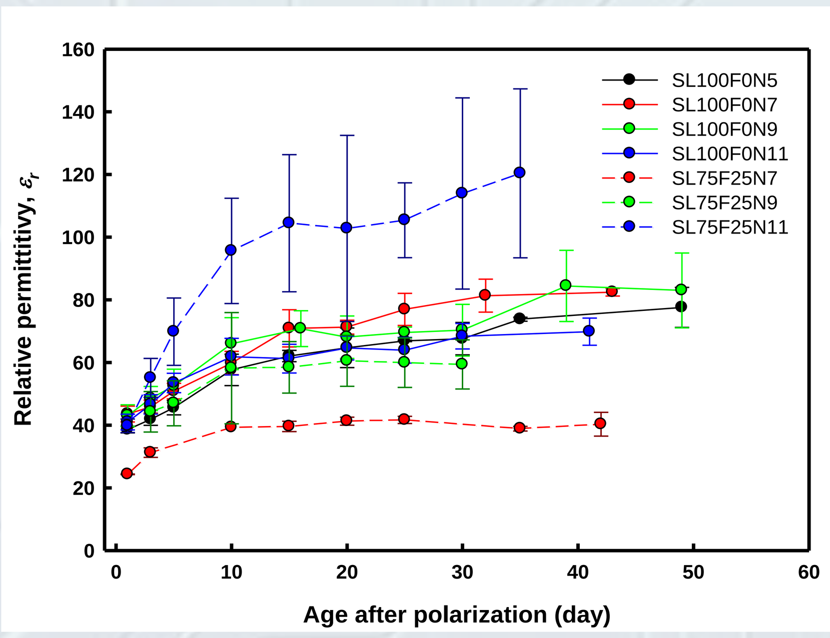
▲ Piezoelectric strain factor

- **GGBS systems:**

The GGBS system shows less sensitivity to alkali equivalent, with d_{33} values **between 20 and 30 pC/N.**

- **FA-GGBS systems:**

With FA, alkali equivalent shows high sensitivity of d_{33} in the FA-GGBS system, with d_{33} = **15 pC/N (N = 7%) to 37 pC/N (N = 11%).**



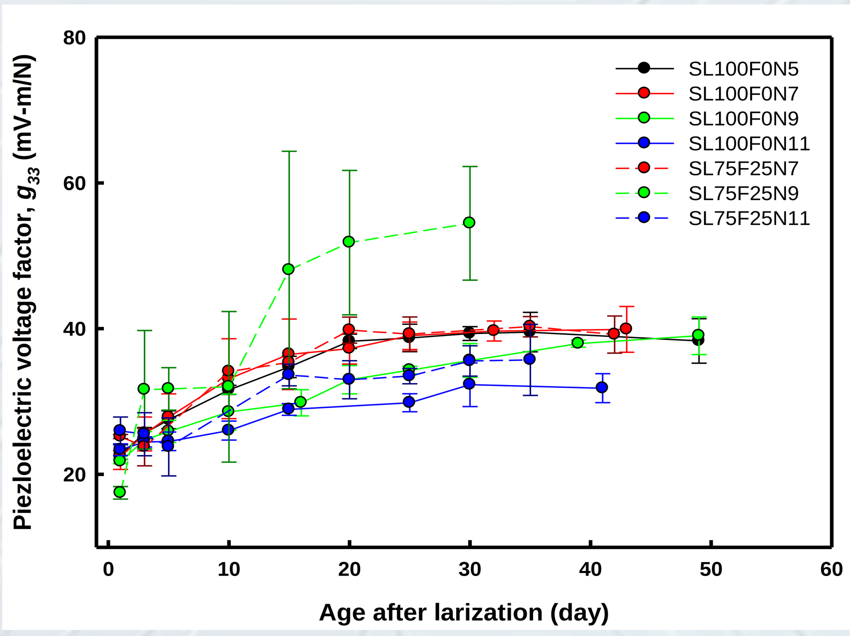
▲ Relative permittivity

- **GGBS systems:**

The alkali equivalent has less effect on the relative permittivity (ε_r) of the GGBS system, with values **between 70 and 85.**

- **FA-GGBS systems:**

The relative permittivity of FA-GGBS systems is sensitive to alkali equivalent, with **40 (N = 7%) to 120 (N = 11%).**



▲ Piezoelectric voltage factor

- **GGBS systems:**

The g_{33} value reaches **40 mV·m/N** for the GGBS system over the N range of **7% to 11%.**

- **FA-GGBS systems:**

The g_{33} reaches an optimal value of **50 mV·m/N at N = 9%.** At **N=11%,** the FA-GGBS systems have a higher relative permittivity (ε_r), and the g_{33} value reduces to **35 mV·m/N.**

CONCLUSIONS

1. Before polarization, the dielectric loss (D) of the GGBS system decreases as the alkali equivalent increases. The FA-GGBS system achieves a minimum D value of approximately 0.12 at N = 7%, which is beneficial for the polarization of facilitation.
2. The dielectric and piezoelectric properties of all PZT/AAM composites reach their stable value after 20 days of polarization.
3. Compared to the GGBS system, the amount of alkali has a more sensitive effect on the relative permittivity of the FA-GGBS system (SL75F25).
4. In FA-GGBS systems, the alkali equivalent has a significant impact on the piezoelectric strain constant (d_{33}). The SL75F25N11 has the highest d_{33} value, approximately 37 pC/N.
5. The g_{33} values of PZT/AAM composite materials are higher than those of conventional PZT ceramic sensors, indicating that the PZT/AAM composite material as a sensing element is suitable for use as a piezoelectric sensor for structural health monitoring.