

Fly ash valorisation in geopolymer synthesis: effect of activator composition and curing conditions on mechanical performance



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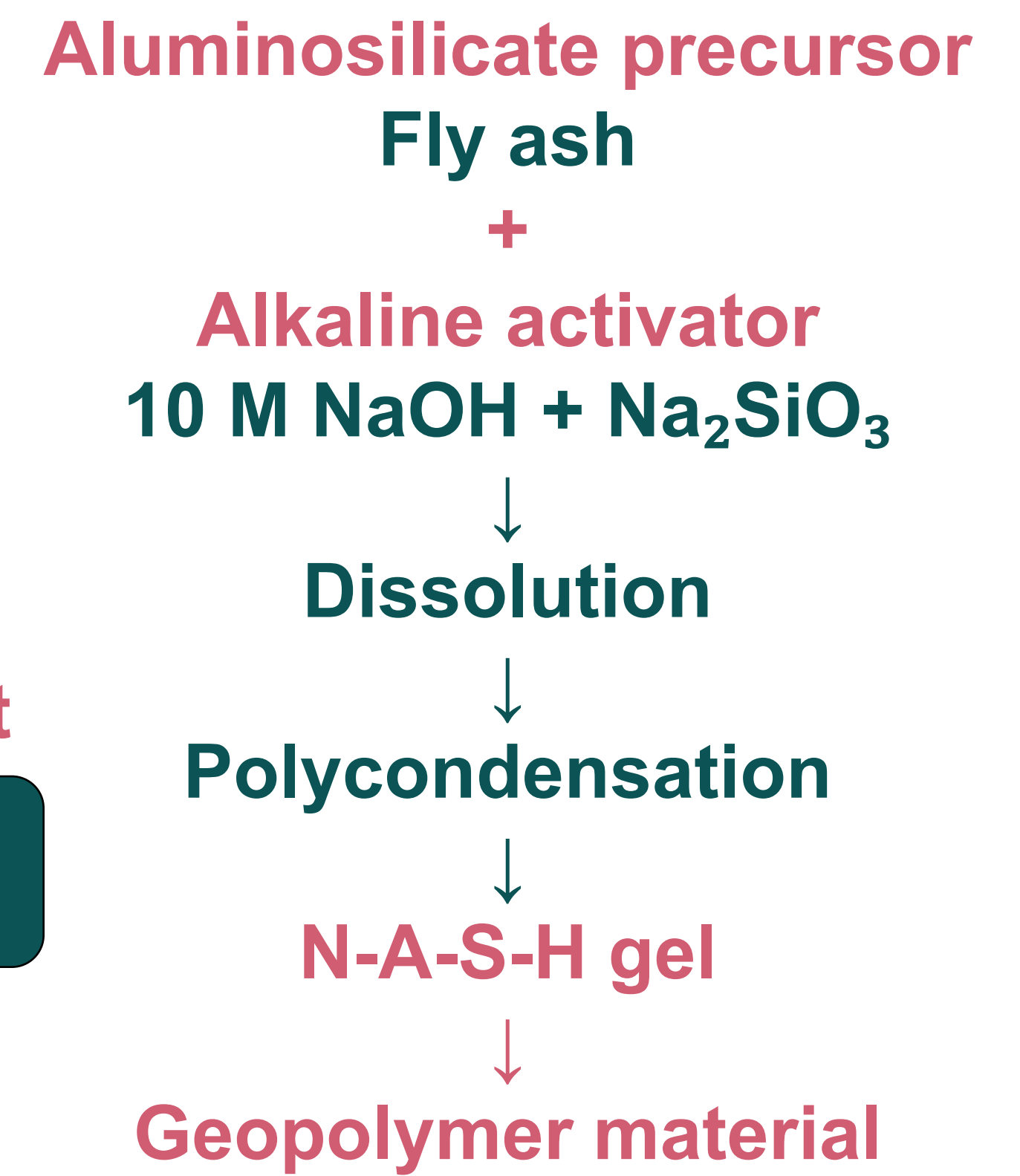
Introduction

The increasing generation of industrial by-products creates significant environmental challenges and highlights the need for sustainable waste valorisation strategies. Fly ash, generated during coal combustion, is considered a valuable anthropogenic aluminosilicate raw material with high potential for geopolymer synthesis.

Geopolymers are inorganic aluminosilicate materials synthesized under highly alkaline conditions through dissolution and polycondensation reactions, leading to the formation of an N-A-S-H gel network. Compared to conventional cement-based materials, geopolymers exhibit lower environmental impact together with favorable mechanical and durability properties.

The properties of geopolymeric materials strongly depend on synthesis parameters, particularly alkaline activator composition and curing conditions. Therefore, this study investigates the influence of NaOH:WG ratio, activator-to-solid ratio, and curing temperature on the mechanical performance of fly ash-based geopolymers.

Fly ash generation → Waste valorisation → Geopolymer materials → Reduced environmental impact



Materials & Methods

Fly ash was used as the aluminosilicate precursor for geopolymer synthesis. The alkaline activator consisted of a 10M NaOH solution combined with sodium silicate solution (water glass, WG). Geopolymer mixtures were prepared using different NaOH:WG ratios and activator-to-solid (A:S) ratios, as presented in Table 1.

The geopolymerization process involved mixing the raw materials, casting the prepared pastes into moulds, and initial curing for 24 h. Subsequently, the samples were thermally cured at 40°C, 60°C, or 80°C for an additional 24 h and then stored at room temperature (23°C) until testing.

Mechanical performance was evaluated based on compressive and flexural strength measurements performed after 7, 14, 21, and 28 days of curing. Additionally, scanning electron microscopy (SEM) analysis was conducted for raw fly ash and selected geopolymer samples to investigate the development of microstructure and geopolymeric gel formation during curing.

ID	A:S	NaOH:WG	CT, °C	ID	A:S	NaOH:WG	CT, °C
G_0,3_1_40	0,3	1	40	G_0,35_1_80	0,35	1	80
G_0,3_1_60	0,3	1	60	G_0,35_1,5_40	0,35	1,5	40
G_0,3_1_80	0,3	1	80	G_0,35_1,5_60	0,35	1,5	60
G_0,35_0,5_60	0,35	0,5	60	G_0,4_1_60	0,4	1	60
G_0,35_0,5_80	0,35	0,5	80	G_0,4_1_80	0,4	1	80
G_0,35_1_40	0,35	1	40	G_0,45_1_60	0,45	1	60
G_0,35_1_60	0,35	1	60	G_0,45_1_80	0,45	1	80

Table 1. Summary of sample preparation conditions

Results & Discussion

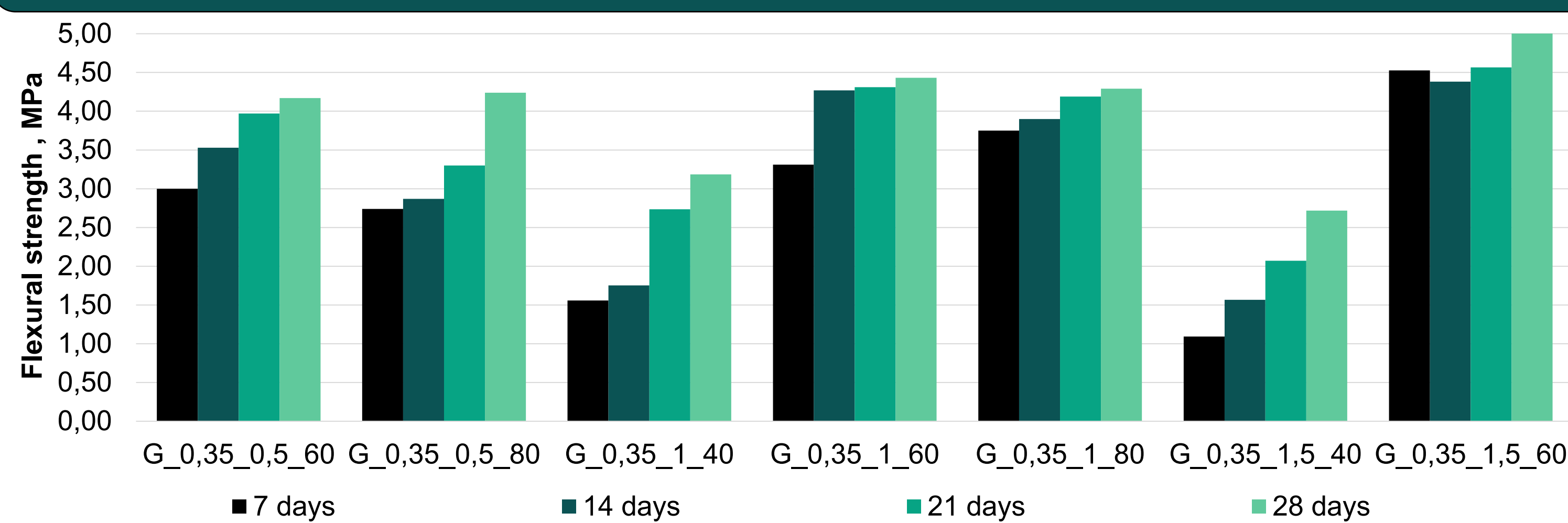


Figure 1: Flexural strength results for samples with an A:S ratio of 0.35

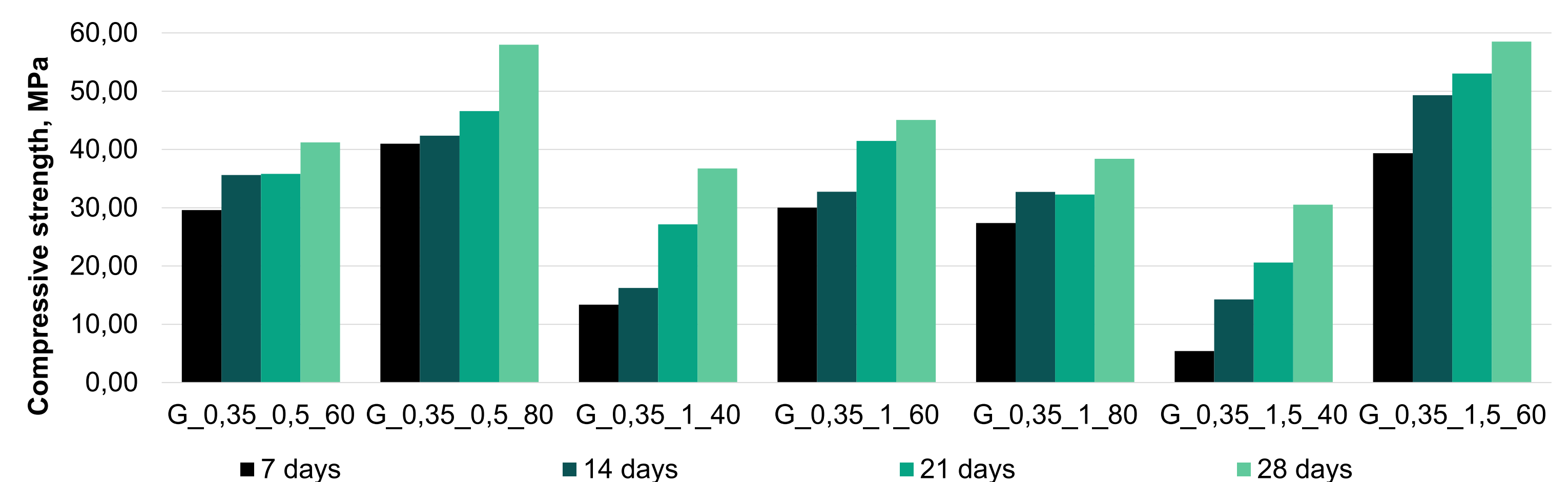


Figure 2: Compressive strength results for samples with an A:S ratio of 0.35

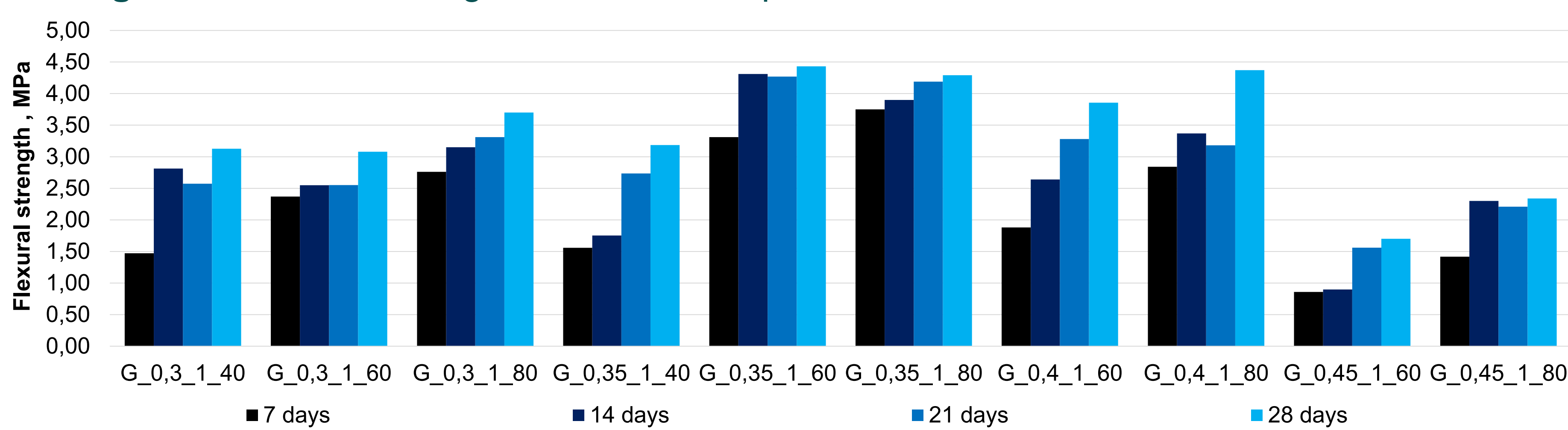


Figure 3: Flexural strength results for samples with a NaOH:WG ratio of 1

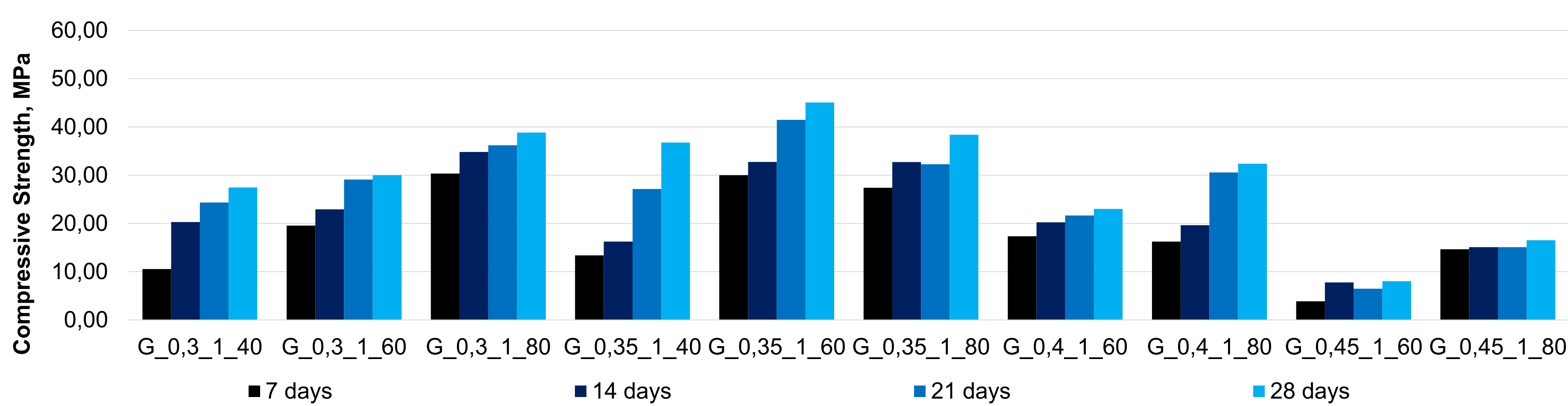


Figure 4: Compressive strength results for samples with a NaOH:WG ratio of 1

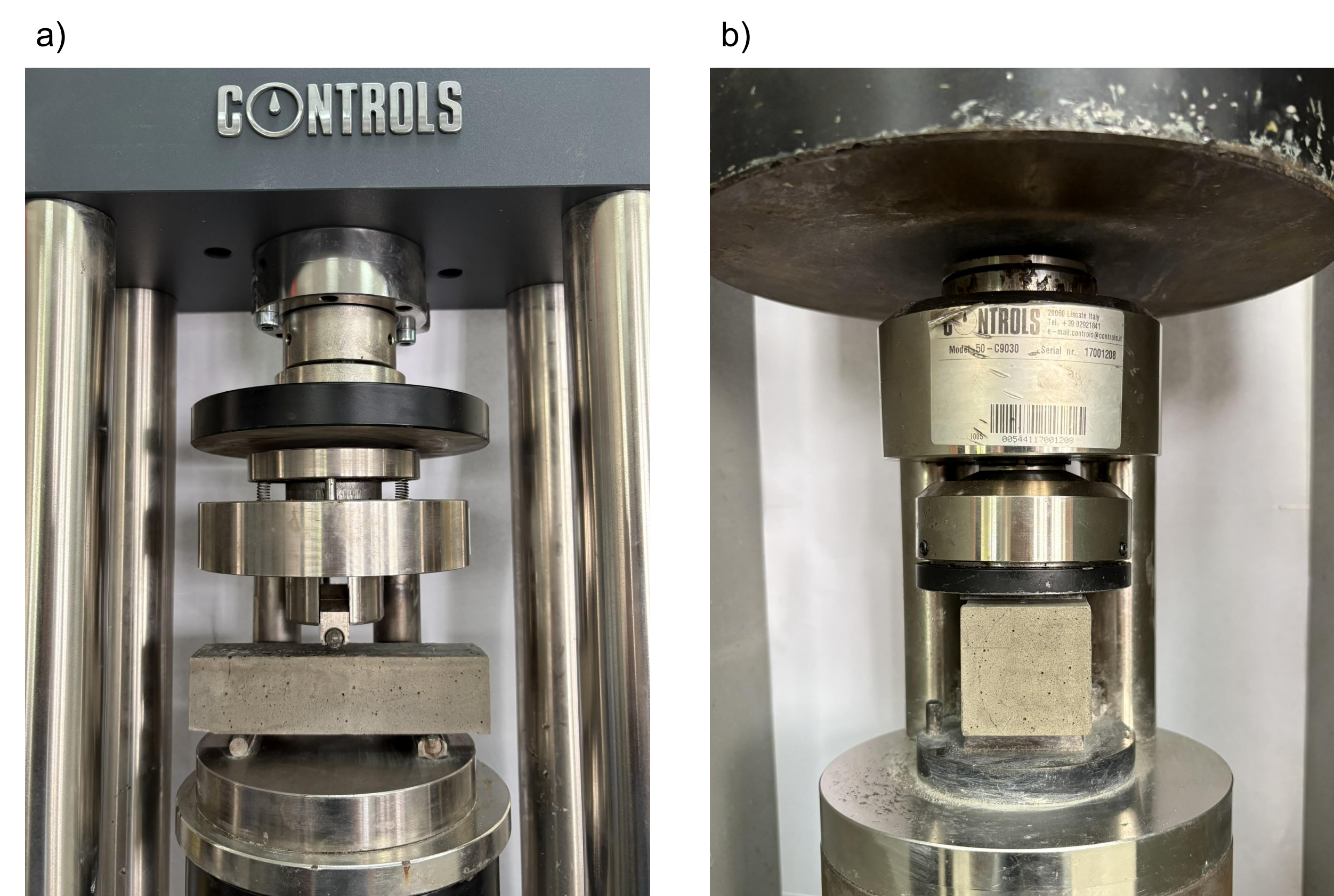


Figure 5: Mechanical testing of geopolymer specimens: a) flexural strength test; b) compressive strength test

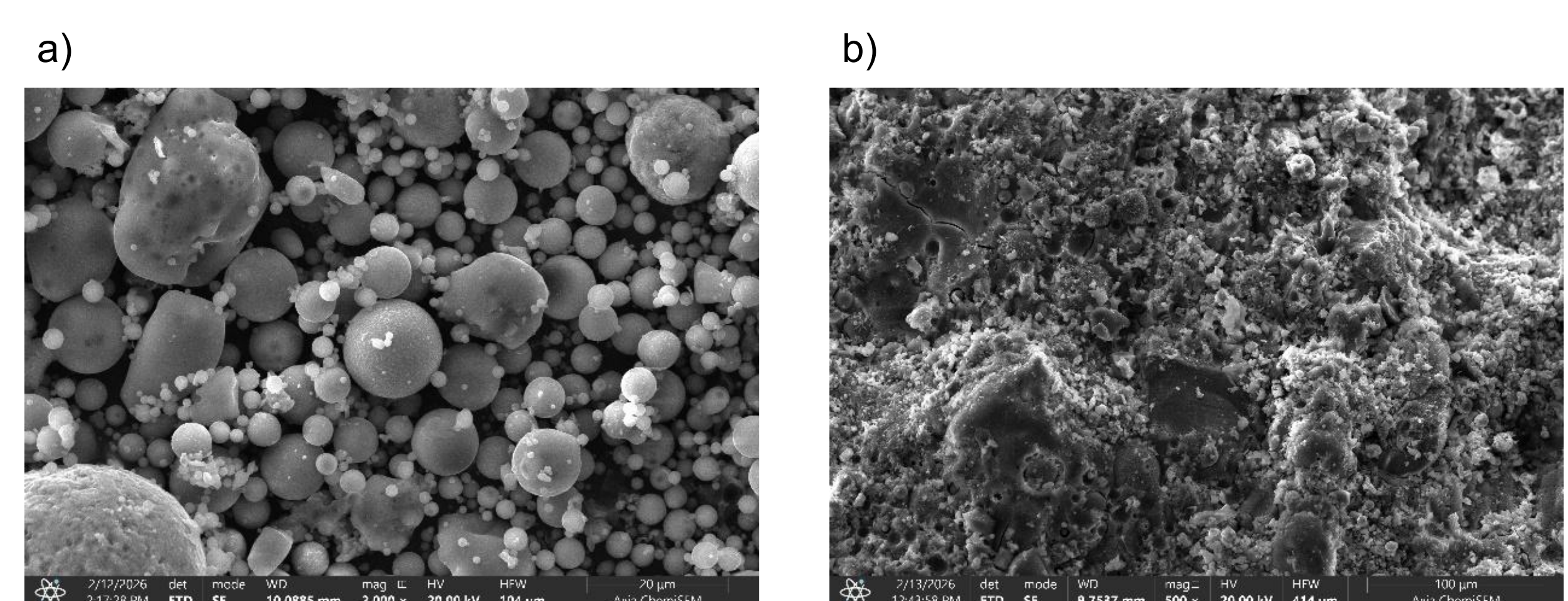


Figure 6: SEM images: a) fly ash; b) geopolymer G_0.35_1_60 after 28 days of curing

Conclusions

- The conducted research confirmed the potential of fly ash as a valuable precursor for geopolymer synthesis and the production of alternative binder materials with promising mechanical properties.
- The obtained results demonstrated that curing time positively influenced the development of both compressive and flexural strength during geopolymer maturation. Additionally, both the NaOH:WG ratio and curing temperature affected the mechanical performance of the produced materials.
- SEM observations confirmed the characteristic spherical morphology of fly ash particles and revealed the gradual formation of a compact geopolymeric gel structure during curing.