

REINFORCING FAST-SETTING GEOPOLYMERS WITH GEOTEXTILES

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Abstract. *Geopolymers are cementing materials which depict a number of advantages compared to Portland cement. For instance, contrary to Portland, geopolymers are synthesized at room temperature, thus significantly reducing the emission of CO₂ to the atmosphere. Moreover, the composition and synthesis reactions can be tailored to adjust the setting time of the material as well as its compressive mechanical strength. It is then possible to produce geopolymeric cements with short setting times and high compressive strength, although relatively brittle. The objective of the present study was to produce and characterize composite materials by reinforcing fast-setting geopolymeric matrixes with polypropylene, in an attempt to improve the toughness and tensile strength of the material. Geosynthetics and geotextiles have been increasingly used to reinforce engineering structures, providing higher strength and better toughness. In particular, polypropylene nonwoven and geomats depict other attractive properties such as low density, durability, impact absorption and resistance to abrasion. Fast-setting geopolymers were then synthesized and reinforced with polypropylene nonwoven and geomats. The mechanical strength of the materials, both plain and reinforced, was characterized. The results confirmed that it is possible to improve both the mechanical strength and fracture resistance of geopolymeric cements by adding polypropylene geotextiles.*

Keywords: *geopolymers, fast-setting, geomat, nonwoven*

1. INTRODUCTION

The use of new construction materials include the so-called geopolymers, inorganic aluminosilicates polymerized by alkaline ions (Davidovits, 1991). Geopolymeric cements depict a number of advantages over conventional Portland-based materials. Firstly, the reactions involved in the production of geopolymers, namely geosynthesis, occur at room temperature, i.e., without emission of CO₂ to the atmosphere. The starting materials, mainly metakaolin, and hydroxides or silicates, react to form a tridimensional network of silicate units joined by alkaline ions. Furthermore, the composition and geosynthesis parameters can be adjusted to determine both the mechanical properties and setting time of a geopolymer. In particular, geopolymers can be produced to depict significantly low setting times and withstand loads after short periods of cure. The setting rate is mainly determined by the nature of the alkaline environment and the molar ratio between activating species (Marinho *et al.*, 2004; Marinho *et al.*, 2006 and Nobrega *et al.*, 2006). A previous study revealed that KOH-based geopolymers can start harden after approximately 35 – 60 min and complete the process after approximately 55 – 95 min. The density of such materials varied from 1.78 to 1.81 g/cm³ (Nobrega *et al.*, 2006). On the downside, the resulting geopolymers were rather brittle.

Modern construction structures have been commonly reinforced by the addition of a number of fibrous materials dispersed in brittle matrixes, including fiberglass and carbon fibers (Balaguru and Slattum, 1995, Bentur and Mindess, 1990). Alternatively, geosynthetics and geotextiles, such as polypropylene nonwoven and geomats have been increasingly used to reinforce engineering structures, providing higher tensile strength and better fracture toughness, combined to other attractive properties such as low density, durability, impact resistance, and long-term performance (Abramento, 1995 and Palmeira, 1998). Therefore, the objective of the present study was to produce fast-setting geopolymeric matrixes and reinforce them by the addition of polypropylene nonwoven and geomats. Initially, the composition of the geopolymeric matrix was adjusted to provide adequate flowing behavior to pour the cement into the molds containing the reinforcement without significantly retarding the setting time. Subsequently, the mechanical behavior of both plain and reinforced geopolymers was evaluated by diametral compression tests as a function of the curing time.

2. MATERIALS AND METHODS

Geopolymeric cements were synthesized from metakaolin (Metacaulim HP do Brasil Ltda), K₂SiO₃ (Diatom Mineração Ltda), and KOH (Vetec Química Fina Ltda). Four metakaolin:activator molar ratios were studied, i.e., 1: 0.8,

1: 1.5, 1: 1.6, and 1: 1.8, as summarized in Tab. 1. The concentration of the KOH solution was previously adjusted to 15 M (Nobrega *et al.*, 2006). The composition of the geopolymeric matrix was selected based on the mixing behavior, determination of setting time using a Vicat needle apparatus, and rheological parameters using a direct reading viscosimeter (Chandler Eng model 3500). The plastic viscosity and yield stress were calculated by fitting the experimental plots of shear stress vs. shear rate using the Bingham model. The correlation coefficients (r^2) are also reported. Geopolymeric slurries were then prepared and poured into cylindrical steel molds (50 mm diameter x 100 mm height) containing either polypropylene geomats (Fig. 1a) or nonwoven (Fig. 1b). All mats were placed in the same manner as to reinforce the samples along their height. Finally, both plain and reinforced samples were submitted to diametral compression tests (Shimadzu AG-I) after curing for up to 182 days.

Table 1: Geopolymeric matrix compositions investigated.

Constituent	1:0.8	1:1.5	1:1.6	1:1.8
Metakaolin (g)	800.0	800.0	800.0	800.0
K ₂ SiO ₃ (g)	213.3	400.0	426.7	480.0
KOH (g)	426.7	800.0	853.3	960.0

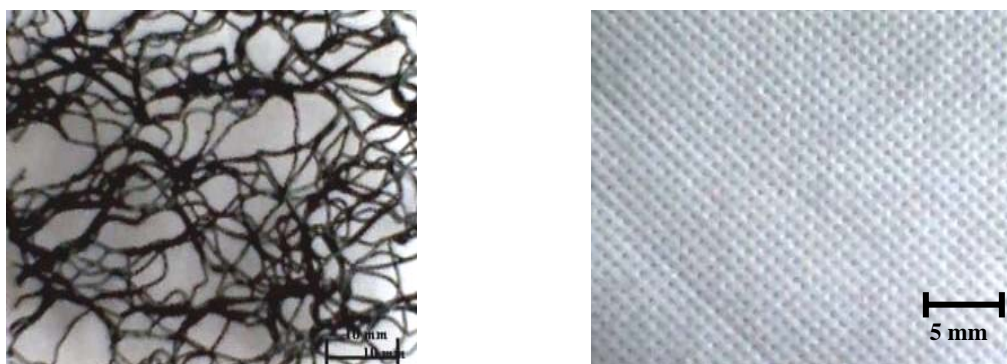


Figure 1: Polypropylene (a) geomat and (b) nonwoven.

3. RESULTS

The geopolymeric composition with metakaolin:activator ratio of 1:0.8 reacted instantly upon mixing the starting materials. The slurry began to set right during homogenization and hardened after 25 min. Due to its high plastic viscosity, it was not possible to pour the geopolymeric slurry into the molds containing the reinforcements. Although strong fast-setting geopolymeric cements can be produced using such composition, these cements were not further evaluated in the scope of the present study. All other compositions depicted lower viscosity and could be molded and reinforced. The corresponding rheological parameters are listed in Tab. 2. The experimental data was fitted using Bingham's model resulting in reasonable values of the correlation coefficient, R^2 , included in Tab. 2.

Table 2: Rheological behavior of geopolymeric slurries as a function of metakaolin:activator ratio.

Parameter	1:0.8	1:1.5	1:1.6	1:1.8
Plastic viscosity (Pa.s)	-	0.11	0.08	0.05
Yield stress (Pa)	-	4.43	2.23	1.53
R^2	-	0.9952	0.9983	0.9987
Setting time (min)	25	80	100	160

The viscous aspect of each of the slurries listed in Tab. 2 can be visualized in Fig. 2. Fluid slurries were obtained using metakaolin:activator ratios of 1:1.5, 1:1.6 and 1:1.8. Indeed, the fluidity of the slurry increased with increasing the activator content. The water to cement ratio was adjusted for each of the slurries and increased from 1:0.8 to 1:1.8, as the concentration of liquid activator increased.

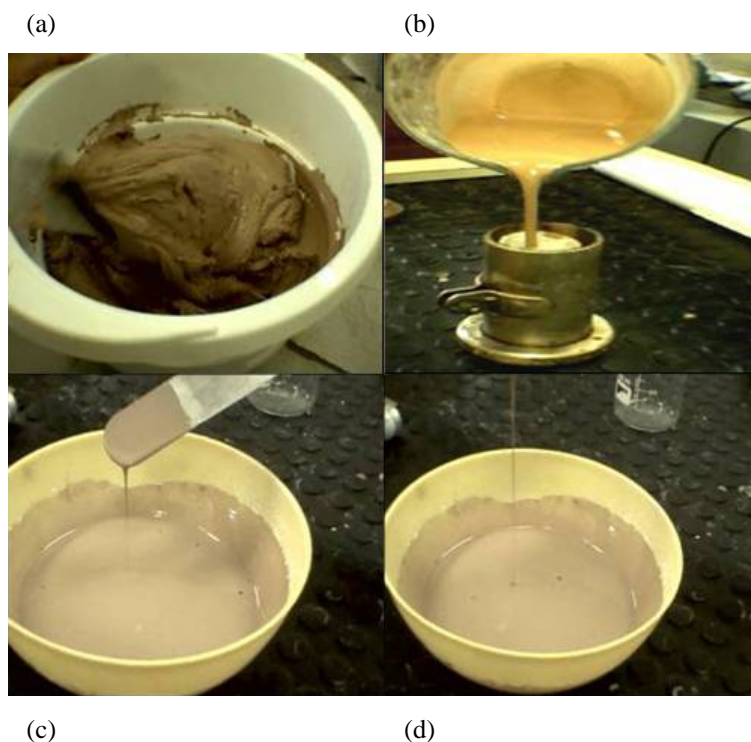


Figure 2: Mixing geopolymeric slurries with metakaolin:activator ratio of (a) 1:0.8, (b) 1:1.5, (c) 1:1.6 and (d) 1:1.8.

Diametral compression tests were carried out on both plain and reinforced geopolymeric cement samples after curing for 48 h at room temperature (Fig. 3). The results revealed that the reinforced samples continued to deform beyond the point of initial rupture, as a result of the ongoing interaction between the geopolymeric cement and the reinforcing phase. As the displacement of the testing machine increased, the geopolymeric matrix continuously cracked, but remained attached to the reinforcing phase. Charge transfer to the polypropylene reinforcement allowed deformation and cracking of the composite at lower loads, as it can be seen from the plots of geopolymeric samples reinforced with polypropylene geomats (orange curves in Fig. 3). Geopolymers reinforced with nonwoven polypropylene showed increased cracking resistance during fracture, due to the continuous and closed structure of that reinforcing phase.

The values of the diametral compressive strength were generally higher for reinforced samples. Both polypropylene nonwoven and geomats provided improved fracture energy; however, the strength was higher for samples reinforced with nonwoven. Samples synthesized with metakaolin:activator ratio 1:1.5 depicted the best results in terms of strength and improved fracture energy. This is probably due to the lower content of water required to produce this cement. Further reducing the amount of water (ratio of 1:0.8) drastically reduced the mixing ability of the slurry, as pointed out earlier. The maximum measured strength of the geopolymer with ratio of 1:1.5 increased from 1.5 MPa (unreinforced) to 2.1 MPa (reinforced with nonwoven).

Samples with ratio of 1:1.5 were also cured for longer times, i.e., up to 182 days and analyzed by diametral compression tests. Four samples were molded and tested after each curing time. The results revealed that the strength of geopolymers reinforced with nowoven decreased after longer curing periods, whereas that of geopolymers reinforced with geomats remained virtually unchanged. This is probably due to the development of long-term stronger adherent interfaces between the geopolymeric matrix and polypropylene geomats, as a consequence of the open geomat fiber structure, which improves the flowing of the slurry and the mechanical interlocking between matrix and reinforcement. The results obtained from the diametral compression tests carried out after 182 days are shown in Fig. 4. As it can be seen, higher strength values were obtained for samples reinforced with geomats, nevertheless, the morphology of nonwoven polypropylene resulted in improved overall deformation, prior to total damage of the sample upon mechanical loading. The reproducibility of the results was also tested and shown in Fig. 4. All samples submitted to the same curing conditions depicted similar behavior under diametral compression stresses.

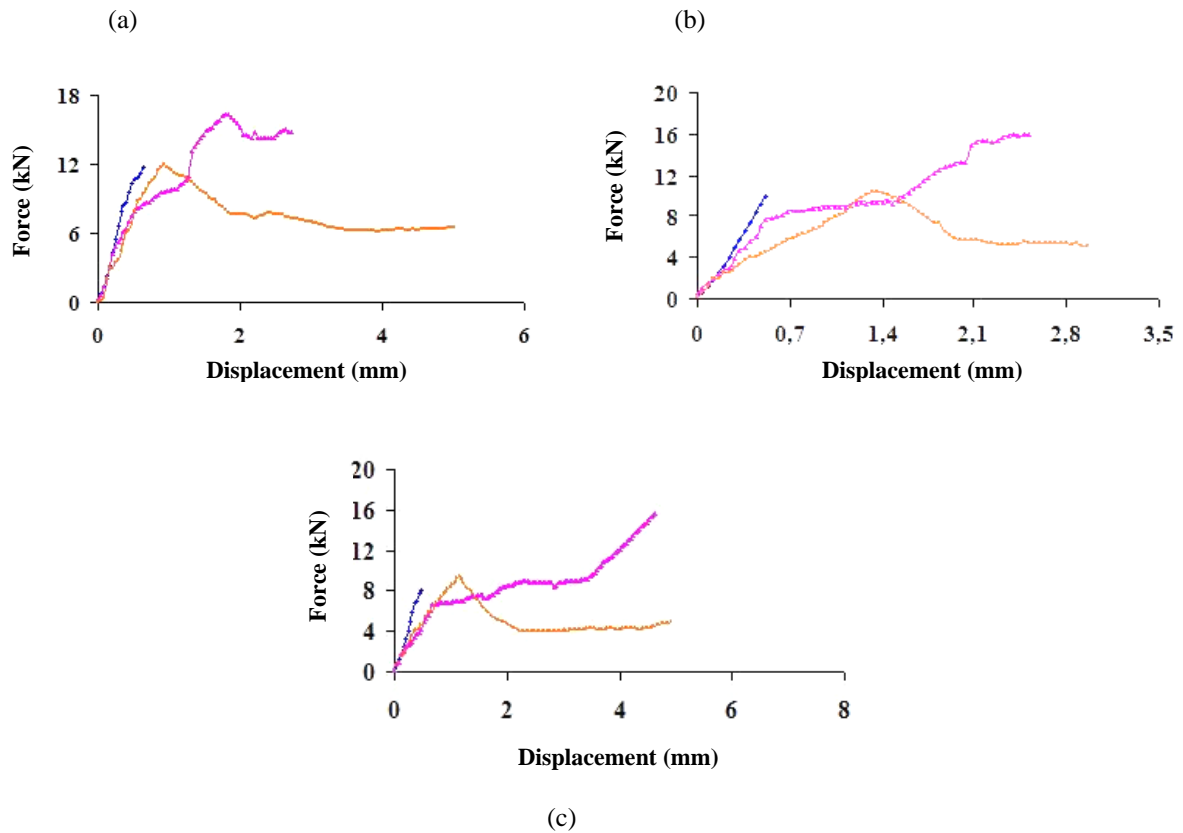


Figure 3. Plots of diametral compression tests of plain and reinforced geopolymers as a function of metakaolin:activator ratio. (a) 1:1.5, (b) 1:1.6 and (c) 1:1.8. (blue: no reinforcement; orange: geomat, purple: nonwoven).

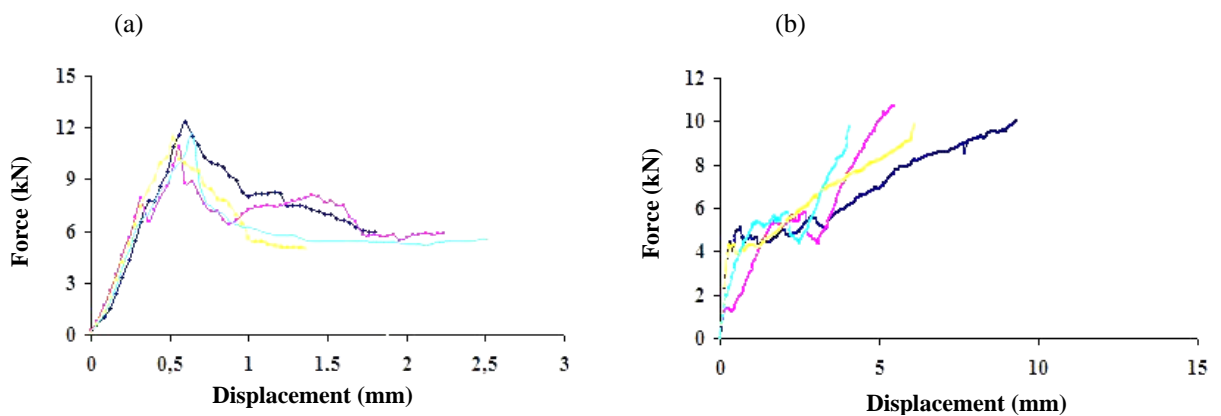


Figure 4: Plots of diametral compression tests of geopolymers with ratio 1:1.5 cured for 182 days and reinforced by polypropylene (a) geomat and (b) nonwoven. Individual curves for each sample tested are shown.

4. CONCLUSIONS

Geopolymeric cements were reinforced by polypropylene nonwoven and geomats. The composition of the cement determined both the setting time and the viscosity of the geopolymeric slurry. Short setting times were accompanied by high plastic viscosity, thus preventing molding and reinforcing. The metakaolin:activator ratio was adjusted to 1:1.5 to conciliate short setting time and adequate fluidity. Reinforcing such geopolymers with polypropylene provided higher fracture energy compared to plain samples. Nonwoven-reinforced geopolymers depicted higher initial strength;

however, after longer curing periods, geomat-reinforced materials displayed slightly higher diametral compression strength but significantly better deformation ability.

5. ACKNOWLEDGEMENTS

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6. RESPONSIBILITY NOTICE

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