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Flexural strength of plain and fibre-reinforced boroaluminosilicate geopolymer

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HIGHLIGHTS

- Anhydrous borax was used as a part of alkali activator of geopolymer pastes.
- Formation of B—O bond helped geopolymers to gain high strengths.
- Reinforced and plain boroaluminosilicate geopolymers reveal high flexural strengths.

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ABSTRACT

In the present work, flexural strength of plain and fibre-reinforced boroaluminosilicate geopolymers is studied. Traditional aluminosilicate geopolymers are produced by alkali activation of an aluminosilicate source. Alkali activator is normally made by mixing a high alkali solution (such as sodium hydroxide) and a silica-rich source (such as sodium silicate). Alkali activation of fly ash in this study, to fabricate boroaluminosilicate binders, was performed by mixtures of anhydrous borax and sodium hydroxide. Flexural strength of the specimens in unreinforced and reinforced conditions was measured by three-point bending. Reinforced specimens were prepared by using 2, 3 and 5 wt.% of steel fibres, with length and diameter of 30 and 0.5 mm respectively. The highest flexural strength of unreinforced specimens was 9.5 ± 0.4 MPa, with borax to NaOH solution weight ratio of 0.912 and alkali activator to fly ash weight ratio of 0.9. Reinforcing of this mixture by 5 wt.% of steel fibres resulted in the highest flexural strength, 11.8 ± 0.9 MPa. Maximum and minimum average increase of flexural strength of about 47% and 5% were achieved by adding 5 and 2 wt.% of steel fibres to some mixtures respectively. Results indicated the ability of these new classes of construction materials for using in flexural load-bearing sections in both unreinforced and reinforced situations.

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1. Introduction

Alkali activated binders (geopolymers) are increasingly developed nowadays and have attracted a great deal of attentions because of their eco-friendly nature [1,2]. These cement-free constructional materials are normally made by alkali activation of an aluminosilicate source such as fly ash [3]. Normal alkali activators are combinations of a high alkali solution such as sodium hydroxide (NaOH) or potassium hydroxide (KOH), and a silica-rich source with high content of amorphous silica such as sodium silicate or potassium silicate solutions. Alkali activation of fly ash results in production of geopolymeric compounds, which is normally conducted at slightly above ambient temperatures (e.g. 60 °C) [4]. General formula of an aluminosilicate binder is $nM_2O{\cdot}Al_2O_3{\cdot}xSiO_2{\cdot}yH_2O$, where M is an alkali element such as potassium or sodium [5]. However, some attempts have been made to produce geopolymers by utilizing other sources, and evidence of production of geopolymers with reasonable performance can be found in Refs. [6–8]. The current research is inspired from Williams and van Riessen work [8], where borosilicate geopolymers were made by alkali activation of silica fume. Alkali activation of their silica source material was performed by a mixture of NaOH and anhydrous borax ($Na_2B_4O_7$), and compressive strength of about 57 MPa was reported to be achievable. In the present study, same alkali activator has been used for activation of fly ash and hence, it is anticipated that boroaluminosilicate geopolymers form. Formation of B—O bonds has been shown in the authors' previous work [9]. In that work, possibility of achieving boroaluminosilicate geopolymers with higher strength than

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Table 1
Chemical composition of fly ash.

Oxide	Wt.%
SiO_2	65.5
Al_2O_3	26.7
Fe_2O_3	1.85
CaO	2.26
SO_3	0.43
Na_2O	0.38
L.O.I.	0.9

aluminosilicate one from a specific fly ash source was achieved. It was suggested that main aluminosilicate geopolymeric compounds change slightly to boroaluminosilicate compounds as a result of formation of B—O bonds. Additionally, microstructure of the considered specimens showed different nature with respect to aluminosilicate geopolymers. Therefore, boroaluminosilicate geopolymers seems to have potential for considering as a new class of construction materials for further studies.

Although reinforcing of geopolymers by different fibres has not been widely reported, it may be of interest and of many unknown features. Ohno and Li [10] studied compressive and tensile strength of randomly oriented short Poly-Vinyl-Alcohol (PVA) fibre-reinforced geopolymers. Tensile strain hardening behaviour with very high ductility of over 4% was one of the interesting findings of their reinforced composite. While Puertas et al. [11] reported that incorporation of polypropylene fibres causes improvement of

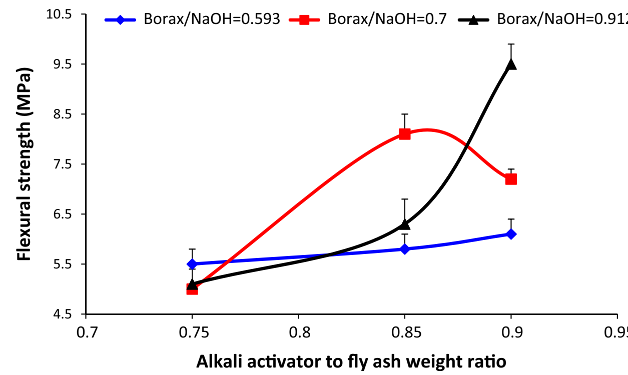

Fig. 1. Flexural strength of G series (unreinforced) specimens.

Table 2
Mixture proportions of unreinforced geopolymer pastes.

Sample designation	Borax to NaOH solution weight ratio	Alkali activator to fly ash weight ratio	Content of fly ash (kg/m^3)	Content of borax (kg/m^3)	Content of NaOH flakes (kg/m^3)	Content of water (kg/m^3)	Content of superplasticizer (kg/m^3)
G1	0.593	0.75	1312	366	198	416	4.20
G2	0.593	0.80	1276	380	205	431	4.35
G3	0.593	0.90	1208	405	219	459	4.64
G4	0.700	0.75	1312	405	185	390	3.94
G5	0.700	0.80	1276	420	192	404	4.08
G6	0.700	0.90	1208	448	205	431	4.35
G7	0.912	0.75	1312	469	165	347	3.5
G8	0.912	0.85	1241	503	177	371	3.75
G9	0.912	0.90	1208	519	182	383	3.87

Table 3
Mixture proportions of reinforced geopolymer pastes.

Sample designation	Borax to NaOH solution weight ratio	Alkali activator to fly ash weight ratio	Percentage of steel fibres (wt.%)	Content of materials (kg/m^3)					
				Fly ash	Anhydrous borax	NaOH flakes	Water	Superplasticizer	Steel fibres
RG1	0.593	0.75	2	1286	359	194	408	4.12	45.9
RG2	0.593	0.80	2	1250	372	201	422	4.26	45.9
RG3	0.593	0.90	2	1184	397	215	450	4.55	45.9
RG4	0.700	0.75	2	1286	397	181	382	3.86	45.9
RG5	0.700	0.80	2	1250	412	188	396	4.00	45.9
RG6	0.700	0.90	2	1184	439	201	422	4.26	45.9
RG7	0.912	0.75	2	1286	460	162	340	3.43	45.9
RG8	0.912	0.85	2	1216	493	173	364	3.68	45.9
RG9	0.912	0.90	2	1184	509	178	375	3.79	45.9
RG10	0.593	0.75	3	1273	355	192	404	4.07	68.9
RG11	0.593	0.80	3	1238	369	199	418	4.22	68.9
RG12	0.593	0.90	3	1172	393	212	445	4.50	68.9
RG13	0.700	0.75	3	1273	393	179	378	3.82	68.9
RG14	0.700	0.80	3	1238	407	186	392	3.96	68.9
RG15	0.700	0.90	3	1172	435	199	418	4.22	68.9
RG16	0.912	0.75	3	1273	455	160	337	3.40	68.9
RG17	0.912	0.85	3	1204	488	172	360	3.64	68.9
RG18	0.912	0.90	3	1172	503	177	372	3.75	68.9
RG19	0.593	0.75	5	1246	348	188	395	3.99	115
RG20	0.593	0.80	5	1212	361	195	409	4.13	115
RG21	0.593	0.90	5	1148	385	208	436	4.41	115
RG22	0.700	0.75	5	1246	385	176	371	3.74	115
RG23	0.700	0.80	5	1212	399	182	384	3.88	115
RG24	0.700	0.90	5	1148	426	195	409	4.13	115
RG25	0.912	0.75	5	1246	446	157	330	3.33	115
RG26	0.912	0.85	5	1179	478	168	352	3.56	115
RG27	0.912	0.90	5	1148	493	173	364	3.68	115

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