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Comparative strain and deflection hardening behaviour of polyethylene fibre reinforced ambient air and heat cured geopolymer composites

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HIGHLIGHTS

- Heat and ambient cured geopolymer composites exhibited strain hardening behaviour.
- Heat and ambient cured geopolymer composites exhibited deflection hardening behaviour.
- Optimum volume fraction of PE fibre to reinforced geopolymer composite is reported.
- Deflection of ambient cured geopolymer composite is higher than heat cured counterpart.

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ABSTRACT

This paper compares strain hardening and deflection hardening behaviour of polyethylene (PE) fibre reinforced two types of geopolymer composites. The first composite is heat cured fly ash based geopolymer composite while the other is ambient air cured fly ash and slag blended geopolymer composite. Comparison is also made with counterpart ordinary Portland cement (OPC) based composite. Effect of different volume fractions of PE fibre on compressive strength, strain hardening and deflection hardening behaviour of above three composites is evaluated and a critical volume fraction of PE fibre is identified. Results show that both heat and ambient cured geopolymer composites exhibited better strain hardening and deflection hardening behaviour than their counterpart OPC based composite containing same volume fraction of PE fibre. Results also show that the geopolymer composites and cement composite containing PE fibre volume fractions of 0.75–1.0% exhibit the highest ultimate tensile strain, deflection at peak load and maximum number of multiple cracks than other fibre contents. Compressive strength of OPC composite is higher than that of both geopolymer composites. Among geopolymer composites, the ambient cured geopolymer (AGP) composite exhibited much higher deflection capacity at peak load than heat cured geopolymer (HGP) under three-point load. Similar behaviour is also observed in uni-axial tension. Scanning electron microscopic analysis shows adherence of higher amount of cement matrix and geopolymer gel on PE fibre in cement and heat cured geopolymer composite that that on PF fibre in ambient cured geopolymer composite. This indicates the likely hood of higher frictional bond of PE fibre with matrix in cement and heat cured geopolymer than in ambient cured geopolymer.

1. Introduction

Extensive research have been conducted on strain hardening and multiple cracking behaviour of ordinary Portland cement (OPC) based fibre reinforced composites which paved their practical application in different projects in many countries [1–4]. However, they exhibit very high carbon footprint due to high volume of OPC used in the said composites. On the other hand, geopolymer based sustainable binder, alternative to OPC, is developed and showed superior engineering properties [5–7]. Geopolymer exhibits extremely low carbon footprint than the OPC binder [8,9]. Extremely low tensile strength and crack resistance property is inherent to OPC and geopolymer binder. To overcome this limitation short fibres (metallic and polymeric) are added to the composites. Significant improvement in tensile strength and crack resistance are obtained in fibre reinforced geopolymer concrete (FRGC). However, the FRGC exhibits ductility after the peak load resulting in increase in crack width due to pullout of fibres or rupturing of fibres during strain softening or deflection softening. The resulting wide cracks in FRGC material exhibit serious risk in the

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Table 1
Chemical compositions of class F fly ash and blast furnace slag.

Compounds	SiO_2	Al_2O_3	Fe_2O_3	CaO	Na_2O	K_2O	MgO	P_2O_5	SO_3	TiO_2	MnO	LOI
Fly ash	51.11	25.56	12.48	4.3	0.77	0.7	1.45	0.885	0.24	1.32	0.15	0.57
Slag	32.50	13.56	0.85	41.2	0.27	0.35	5.10	0.03	3.2	0.49	0.25	1.11

Table 2
Mix proportions of geopolymer composites.

Types	Series name	PE fibre (by vol)	Mix proportions by wt.					Super-Plasticizer*
			Cement	Fly ash	Slag	Water	Alkali Activator*	
Cement composites (CC)	Control	–	1	–	–	0.4	–	–
	CC-0.5%PE	0.5%	1	–	–	0.4	–	–
	CC-0.75%PE	0.75%	1	–	–	0.4	–	–
	CC-1.0%PE	1.0%	1	–	–	0.4	–	–
	CC-1.5%PE	1.5%	1	–	–	0.4	–	3.5%
Ambient Cured Geopolymer (AGP)	Control	–	–	0.6	0.4	–	0.4	–
	AGP-0.5%PE	0.5%	–	0.6	0.4	–	0.4	3.5%
	AGP-0.75%PE	0.75%	–	0.6	0.4	–	0.4	3.5%
	AGP-1.0%PE	1.0%	–	0.6	0.4	–	0.4	3.5%
	AGP-1.5%PE	1.5%	–	0.6	0.4	–	0.4	3.5%
Heat Cured Geopolymer (HGP)	Control	–	–	1	–	–	0.4	–
	HGP-0.5%PE	0.5%	–	1	–	–	0.4	–
	HGP-0.0%PE	1.0%	–	1	–	–	0.4	–
	HGP-1.5%PE	1.5%	–	1	–	–	0.4	1%
	HGP-2.0%PE	2.0%	–	1	–	–	0.4	2%

Note: *Alkali activator = NaOH + Na_2SiO_3; *Na_2SiO_3/NaOH = 2.5.
*Superplasticizer (Reobuild) by wt% of binder.

Table 3
Properties of polyethylene (PE) fibre.

Fibre	Length (mm)	Diameter (mm)	Modulus of elasticity (MPa)	Fibre tensile Strength (MPa)	Density (g/cm^3)	Elongation (%)
Polyethylene	12	0.012	123,000	3500	0.97	–

durability of the structure as aggressive chemicals penetrate easily to cause corrosion of steel or deteriorate matrix of the FRGC.

Highly ductile strain hardening cement based composites exhibiting multiple fine cracks is developed [1] and as well as its geopolymeric version e.g. [10–13]. The geopolymeric version of strain hardening composite is more environmental friendly with significantly lower carbon footprint than its cement based counterpart. Additionally, the durability properties e.g. acid and fire resistance of this composite will be much higher than its counterpart OPC based composite due to poor fire and acid resistance of OPC binder. The strain hardening and deflection hardening geopolymer composites exhibited superior ductility in terms of high tensile strain capacity and deflection at peak load in uni-axial tension and flexure, respectively [11,12]. Steel and polyvinyl alcohol (PVA) fibres are used to reinforce the above ductile geopolymer composites. Steel fibre is considered as high modulus-high strength fibre which result in high ultimate strength with low ductility of the composite and the PVA fibre is considered as low modulus-low strength fibre which result in low ultimate strength with high ductility of the composite.

Polyethylene (PE) fibre is another kind of polymeric fibre whose modulus is about 2–3 times higher than the PVA and tensile strength is similar to or higher than the steel fibre. Therefore, by reinforcing geopolymer matrix with PE fibre exhibiting high strength and high ductility can be achieved simultaneously. A number of research reports the ductile behaviour of PE fibre reinforced cement based composites in uni-axial tension and bending [14,15]. However, very few reports the strain hardening and deflection hardening behaviour of geopolymer composite containing PE fibres [16–18]. For example, Shaikh and Zammar [18] reported strain hardening and deflection hardening behaviour of PE fibre reinforced heat cured fly ash geopolymer composite, while Nematollahi et al. [17] reported the same for fly ash and slag blended geopolymer composite cured in water at control ambient temperature and Choi et al. [16,19] reported strain hardening behaviour of PE fibre reinforced alkali activated slag composite cured in water at ambient temperature which exhibited significantly higher high tensile strength. The alkali activators used in Ref. [16] were calcium hydroxide and sodium sulfate powder. On the other hand, sodium meta-silicate powder was used as alkali activators in Ref. [17]. While the powder alkali activators show advantage of convenient mixing with other ingredients of the composite, however, the exposure of these highly alkaline powder activator to air during dry mixing with source material might possess potential health risk if inhaled by the personnel during mixing of concrete. On the other hand in both above studies the composites were cured in water. For in-situ field application air curing is more convenient than water curing as in many instances continuous water curing is

Table 4
Compressive strength of all composites.

PE fibre vol%	Compressive strength (MPa)		
	Cement based composite	Ambient cured geopolymer composite	Heat cured geopolymer composite
0	38.6	56.7	79.0
0.5	59.1	28.4	71.0
0.75	59.0	35.0	–
1.0	47.0	44.0	48.0
1.5	33.0	45.0	31.0
2.0	–	–	30.0