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Mechanical properties of steel fibre reinforced geopolymer concretes at elevated temperatures

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HIGHLIGHTS

- Mechanical properties of steel FRGC at elevated temperatures are evaluated.
- Simplified models to predict the mechanical properties at elevated temperatures are also proposed.
- Effects of Na- and K-based alkali activators on above geopolymer concretes are also compared.

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ABSTRACT

This paper presents the effects of two types of alkali activators (Na and K-based) on the residual mechanical properties of steel fibre reinforced geopolymer concretes (SFRGC) after exposed to various elevated temperatures and compared with those of steel fibre reinforced concrete (SFRC). Compressive strength, indirect tensile strength and elastic modulus of above three types of steel fibre reinforced concretes are measured after exposure to elevated temperatures of 200, 400, 600 and 800 °C. Results show that the SFRGC containing Na-based activators exhibited much higher residual compressive and indirect tensile strength at all elevated temperatures including at ambient condition than its K-based counterpart and SFRC. However, the retention of residual compressive strengths relative to ambient is comparable in both Na- and K-based SFRGC and both SFRGCs showed original (ambient temperature) compressive strength retention capacity up to about 500 °C temperature. In the case of indirect tensile strength, the K-based SFRGC showed ambient temperature strength retention capacity up to about 700 °C temperature with more than 60% increase in residual indirect tensile strength at 400 °C. In the case of elastic modulus the SFRC, however, showed slightly higher retention capacity than the SFRGC. Good correlations between the indirect tensile strength and the compressive strength and between the elastic modulus and the compressive strength of all three types of fibre reinforced concretes are observed. Existing model to predict the compressive and indirect tensile strengths of SFRGCs is found to underestimates the test results, however, it predicts reasonably well the elastic modulus of SFRGCs. New empirical equations to predict the compressive, indirect tensile strength and elastic modulus of SFRGCs are also proposed. Both SFRGCs also show negligible damage in terms of surface cracking after elevated temperatures heating compared to visible surface cracks in SFRC.

1. Introduction

Fibre reinforced concrete (FRC) has been developed over the last few decades. The primary reason of addition of fibres in concrete is to improve its tensile and flexural strengths and post-cracking ductility. Various types of fibres are used to reinforce the concrete. Among many fibres steel fibres significantly improve the tensile and flexural strength, toughness and ductility of concrete. As a result steel fibre reinforced concrete (SFRC) is widely used in different construction applications, e.g. tunnel lining, airport pavement, impact and blast resistance of important structures, etc. However, the above structures as well as other reinforced concrete structures experience fire during their service life. During fire significantly high temperatures are developed around the structures which damage the concrete through cracking and spalling. In many studies polymeric fibres reinforced concrete shows spalling resistance at fire, however, its post fire residual mechanical properties is of great concern, as these fibres are melt at elevated temperatures or lose their properties significantly if not melted. An advan-

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Table 1
Chemical composition of fly ash (mass %).

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

Table 2
Experimental program and mix proportions.

Series	Mix proportions in kg/m^3										Steel fibre (Vol.%)	Water/ cement ratio	Alkali activator solution/ fly ash ratio
	Ordinary Portland cement	Fly ash	Sand	Coarse aggregate (mm)		Alkali activator				Added Super-plasticizer			
				10	20	Sodium Hydroxide (NaOH)	Potassium Hydroxide (KOH)	Potassium silicate (K_2SiO_3)	Sodium Silicate (Na_2SiO_3)				
1-FRC	408	–	660	467	701	–	–	–	–	–	0.5 and 0.75	0.4	–
2-FRGC(Na)	–	408	660	467	701	41	–	–	122	150 ml	0.5 and 0.75	–	0.4
3-FRGC(K)	–	408	660	467	701	–	41	122	–	–	0.5	–	0.4

tage of steel fibre reinforced concrete (SFRC) at elevated temperatures during fire is their inherent higher melting temperature than the polymeric fibres, due to which the SFRC shows higher retention capacity of its original mechanical properties than its counterpart polymeric fibres reinforced concrete [1]. A number of studies are reported on the effect of elevated temperatures on mechanical properties and failure behaviour of SFRC. Poon et al. [2] evaluated the effects of elevated temperatures of 600 and 800 °C on the compressive strength of SFRC. It is reported that the residual compressive strength of SFRC is about 50% of original after exposure to 600 °C. At 800 °C the residual compressive strength is 25%. Chen and Liu [1] have also reported a similar study but in high strength concrete. They have reported that the residual compressive strengths of SFRC are about 90%, 60% and 38% of the original at 400, 600 and 800 °C, respectively. The authors also measured the residual tensile strengths (splitting) of above FRC and observed similar reduction. In another study, Suhaendi and Horiguchi [3] also reported similar rate of reduction in the compressive and tensile strengths of SFRC at 200 and 400 °C. In a recent study on steel FRC, Dugenci et al. [4] reported about 78–96% reduction in the compressive strength of SFRC at 900–1200 °C temperatures. Kim et al. [5] in their recent study also reported reductions in the compressive strengths of the SFRC at elevated temperatures.

Geopolymer is a sustainable binder which has been in research for last few decades [6]. Research on geopolymer concrete has also gained momentum among concrete researchers due to its environmental friendliness and superior mechanical, durability and fire resistance properties than the ordinary concrete. However, unreinforced geopolymer concrete is still brittle with very low tensile and flexural strengths like the ordinary concrete. In a number of studies various fibres are added to geopolymer concrete to overcome this deficiency. Among various fibres, steel fibre showed significant improvement in the tensile and flexural strength of geopolymer concretes [7,8]. Unlike regular concrete, the geopolymer concrete exhibits superior mechanical properties retention capacity at elevated temperatures during fire as summarised in [9].

While considerable research has been conducted on the effect of elevated temperatures on mechanical properties of SFRC, no such study is so far reported on the steel fibre reinforced geopolymer concrete (SFRGC). Limited research have been conducted on carbon and cotton fibres reinforced geopolymer composites at elevated temperatures [10,11]. Due to higher fire resistance of geopolymer matrix than the cement matrix, the SFRGC is expected to behave better than its counterpart SFRC. This paper presents the comparative behaviour of SFRC and SFRGC after exposure to elevated temperatures of 200, 400, 600 and 800 °C. The effects of two alkali activators namely sodium (Na) and potassium (K) based activators on the residual mechanical properties of SFRGC are also evaluated in this study. The effect of steel fibre reinforcement on the residual mechanical properties of SFRC and SFRGC is also evaluated in this study. Experimental results are also compared with the predictions by existing empirical model for SFRC and Eurocode for concrete at elevated temperatures. Empirical equations to pre-

Fig. 1. Positions of type K thermocouples inside the kiln and in the cylinder.