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Review

Structural performance of reinforced geopolymer concrete members: A review

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HIGHLIGHTS

- Structural performance of geopolymer concrete members is summarized.
- No detrimental effects of using geopolymer concrete in structural members.
- General behaviour is similar with conventional reinforced concrete structural members.
- Design codes for structural member are applicable, but conservative.

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ABSTRACT

Due to the significant benefit of carbon footprint reduction with the use of cement-less geopolymer concrete, researches had shifted their focus towards the study of the behaviour of geopolymer concrete on micro- and macro-scales. The most important application of concrete in building construction is nonetheless reinforced concrete structural members. Therefore, this review aims to summarize and discuss the reported findings on the structural behaviour of geopolymer concrete members in order to give a clearer understanding of effects of such concrete in structural elements. Among the geopolymer concrete members highlighted in this review include reinforced concrete beams, columns, slabs and panels. It is found that generally there is no detrimental effect of using geopolymer concrete as structural member in terms of its load-carrying capacity, and standard codes of practice could be used to safely design the geopolymer concrete members. Nevertheless, it is suggested that further researches may be carried out to provide a more realistic and cost-effective design guidelines for utilizing geopolymer concrete in structural elements so as to expedite the use of such concrete for large-scale field applications in the future.

Contents

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1. Introduction

With the growing environmental and economic concerns associated with conventional concrete-based building materials such as reinforced concrete structures, researchers have been actively involved in exploring possibilities in using alternative materials to address these concerns. For instance, alternative concrete-making materials have been trialled in reinforced concrete structures such as recycled concrete aggregate [1,2] and agriculture waste materials [3], among others, in an attempt to reduce the dependency on conventional concrete constituent materials, which are fast depleting. One of the primary environmental concerns from concrete-based building materials is the high amount of carbon dioxide emission, which arises during the manufacturing of cement. Approximately 5% of the global carbon dioxide emission is contributed by the cement industry. In recent times, a cement-less binder for producing concrete, termed as geopolymer concrete, is fast gaining popularity in concrete research work as the technology eliminates the need for cement. In order to produce geopolymer, a process termed as 'geopolymerization' is required which involves the reaction between aluminosilicate material and alkaline liquids. Common aluminosilicate material used for producing geopolymer is fly ash and slag, which are both industrial by-products and both of these materials have much lower carbon dioxide emission factor compared to cement. It was reported that the use of geopolymer could bring down the overall carbon dioxide emission by up to 64% in comparison with the use of cement [4]. Furthermore, in terms of economic consideration, due to the lower price of fly ash compared to cement, the price of fly ash-based geopolymer concrete could be as low as 10–30% cheaper compared to conventional cement-based concrete after taking into account the price of alkaline liquids [5].

While most of the research works on geopolymer concrete focus on micro-scale investigation, recent researchers on the use of geopolymer concrete extends to the investigation of the structural behaviour of geopolymer concrete in load-bearing members such as reinforced concrete beams, columns, slabs and more. The structural properties of the concrete members is one of the most vital component in effectively introducing such concrete for actual buildings and applications. The conformity of the performance of reinforced geopolymer concrete members with existing design provisions should be ascertained in order to evaluate the feasibility of using these design codes for geopolymer concrete members for the convenience of structural design engineers. In addition, practising engineers would also be able to produce a more realistic, safer and effective design of geopolymer structures in the long run based on knowledge and findings from research works, such as numerical models, empirical equations, appropriate assumptions and safety factors, among others. In view of the importance of the structural aspect of utilizing geopolymer concrete in reinforced concrete structures, this review summarizes and discusses the published findings of research works involving geopolymer concrete structures such as beams, columns, slabs and panels.

2. Summary of literature

2.1. Reinforcing bar-concrete bond

The structural performance of reinforced concrete members depends on the bond between concrete and reinforcement, in which the mechanism of bond influences the embedded length of reinforcing bar and consequently the load-bearing capacity of structural elements, crack opening and spacing [6]. ACI 408R [7] considers the bond strength as one of the structural properties and the understanding of the behaviour is critical to the eventual development of analysis and design basis of the structural member. Because of the difference in terms of chemical reaction and matrix formation of geopolymer concrete compared to conventional cement concrete, the bond properties of geopolymer concrete should be clearly understood before it is considered to be suitable to be used to replace conventional cement concrete in reinforced concrete structures. Reliance on conventional bond equations meant for normal concrete could lead to unsafe design, and this has led to numerous investigations to ascertain the bond behaviour of geopolymer concrete.

Due to the importance of bonding properties for structural members, researches have been undertaken to evaluate the bond strength between reinforcement and geopolymer concrete. The summary of the bond strengths obtained in literatures is given in Table 1. Sofi et al. [8] initiated the research on steel-geopolymer concrete bond behaviour through beam-end testing and direct

Table 1
Summary of reinforcement-geopolymer concrete bond strengths.

Experimental test	Bond strength (MPa)	Type of test	Remarks
Sofi et al. [8]	5.8–13.3 10.5–14.7	Beam-end test Direct pull-out test	Variables: i) Fly ash-slag ratio in binder ii) Type of fly ash iii) Bar diameter
Chang et al. [12]	3.59–8.77	Splice test	Variables: i) Concrete strength ii) Cover/bar diameter ratio iii) Splice length
Sarker [16]	10.61–19.42	Beam-end test	Variables: i) Cover/bar diameter ratio ii) Embedded length iii) Water content
Moser et al. [17]	3.58–19.68	Direct pull-out test	Variables: i) Curing period ii) Coating
Kim et al. [14]	14.48–35.61	Direct pull-out test	Variables: i) Bar diameter ii) Concrete strength
Topark-Ngarm et al. [15]	7.85–14.59	Direct pull-out test	Variables: i) Concentration of NaOH ii) NaOH: Na_2SiO_3 ratio iii) Type of curing
Castel and Foster [18]	24.10–31.90	Direct pull-out test	Variables: i) Curing period
Ganesan et al. [19]	12.73–16.57	Direct pull-out test	Variables: i) Bar diameter ii) Embedded length iii) Steel fibre volume
Maranan et al. [20]	19.39–23.96	Direct pull-out test	GFRP bars used Variables: i) Bar diameter ii) Embedded length
Tekle et al. [21]	9.60–19.60	Direct pull-out test	GFRP bars used Variables: i) Bar diameter ii) Embedded length iii) Compressive strength