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Fracture evaluation of multi-layered precast reinforced geopolymer-concrete composite beams by incorporating acoustic emission into mechanical analysis

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HIGHLIGHTS

- Introducing multilayer geopolymer-concrete composite beam with high ductility.
- Damage evaluation by incorporating stress wave technique and mechanical analysis.
- To distinguish different mode of failures by acoustic emission analysis.

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ABSTRACT

In this study, a multi-layered steel reinforced composite beams which are composed of geopolymer concrete section at tensile zone and Portland cement based concrete at compression are investigated. The beams were tested to failure to compare the toughness, post peak behaviour and failure mode based on the variation of the depth of layers. The mechanical analysis incorporated into acoustic emission technique showed that the geopolymer beam endured more deflection than the ordinary Portland cement based beams, however their ultimate load carrying capacities were quite similar. Further, the composite beams, resulted in transition of failure mode of shear to a flexural.

1. Introduction

Precast reinforced concrete elements have been extensively used in construction over the past decades due to its time and cost effectiveness and higher quality of the products [1]. However, the integrity of components is a main concern in precast structures. To increase the efficiency of the construction, partially precast beams is mostly used so that combination of precast and in situ sections. As a result, the integrity of structure is increased in comparison to those of fully precast systems, while it becomes more economical, faster and easier compare with in situ construction [2]. Partially precast beams are comprised of a section which is fabricated in factory having a part of reinforcements out from the concrete body; this section is placed as the tensile zone (bottom) of the beam. Such sections are transferred to the site and connected to other members using in situ construction to make a uniform structure. In this system, the precast section is designed to assemble fast and to carry the further loads from in situ casting. Fig. 1 shows an example of such beams.

Geopolymer are inorganic aluminosilicate polymeric materials with near ambient curing and hardening temperatures [4]. They were first introduced with the industrial development of new binder in 1972 by Davidovits. Due to their superior properties of high early strength compare with Portland cement, geopolymers are seen as prospective construction materials for precast industry [5–9]. These materials are used to fabricate several precast

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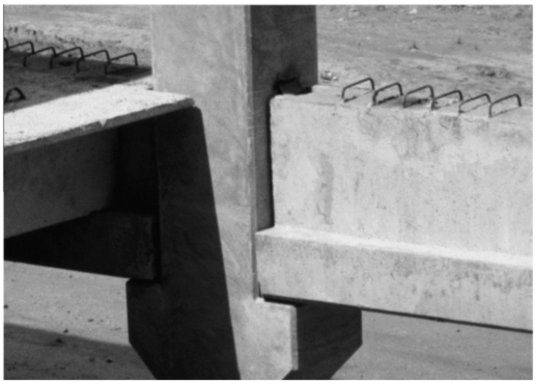

Fig. 1. Application of multi-layers composite inverted T-beam [3].

elements such as retaining walls, sewer pipes, roofing tile, footpaths, pavement, water tanks, precast bridge decks, precast beams, slabs, panels (Melton Library, Melbourne, Australia) and even full scale building(Global Change Institute – University of Queensland) [10–12].

Despite numerous potential geopolymer applications, there are some drawbacks in its widespread utilization and commercialization. As a novel structural binder, the main issue is the compliance of design procedure with the current standards which mostly consider the specific physicochemical properties of Portland cement products. However, alkali-activated concretes are ideally suited to be regulated through a performance-based approach, as per ASTM C1157, which shows the prospective potential for further developments of non-conventional binder systems [12–14]. Furthermore, the promising prefabrication potential of geopolymer paves the way for its industrialization [15].

This research aims to investigate the differences between the performances of ordinary Portland cement (OPC) and geopolymer (GPC) reinforced concrete beams and the effects caused by replacement of GPC in the tensile zone of high strength Portland cement based reinforced concrete beams subjected to a three point bending load from the aspects of specimen ductility, energy absorption, mode of damage and failure. Geopeolymer concrete was replaced to the tensile zone of the beam because of its great potential in high early strength which makes it preferable binder for precast industry. Besides, the top layer of the composite beams were fabricated by OPC which is the conventional material for in situ construction. The results demonstrate that the multi-layer geopolymer composite beams had higher degree of toughness and deformation than the OPC without adverse effects in its maximum load carrying capacity; moreover, the shear based mode of damage in OPC beam changed to a flexural mode in the geopolymer and composite beams.

2. Summary of experimental investigation

2.1. Materials characterization

The batches of low calcium FA (class F) and Portland cement used in this research were collected from Lafarge Malayan Cement Bhd-Malaysia and Tasek Corporation Berhad-Malaysia with the specific gravity of 2.18 and 3.15 respectively. Particle size distributions of fly ash and cement were measured with (Mastersizer, Malvern Instruments, Malvern, UK) and results are shown in Fig. 2. The chemical composition of the materials as determined by X-ray florescence by PANalytical Axios mAX (Netherlands) instrument and LOI value are provided in Table 1.

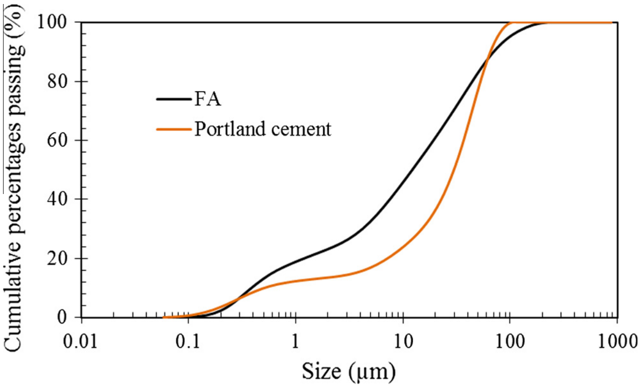

Fig. 2. Particle size distribution of the fly ash and Portland cement.

Table 1
XRF analysis of the fly ash and Portland cement.

Oxide composition	Fly ash (%)	Portland cement (%)
SiO_2	75.76	16.68
Al_2O_3	15.86	4.41
Fe_2O_3	3.90	3.64
K_2O	1.14	0.37
TiO_2	0.97	0.17
CaO	0.95	68.36
SO_3	0.35	4.80
MgO	0.26	1.29
P_2O_5	0.21	0.05
Na_2O	0.16	–
ZrO_2	0.13	–
MnO	0.06	0.10

Local fine aggregate were prepared with the minimum and maximum particle size limited to 300 µm and 4.75 mm, respectively. The coarse aggregate was obtained from Batu Tiga Quarry Sdn Bhd (YTL), Malaysia with a maximum particle size of 10 mm.

To activate the precursor, a mixture of sodium silicate solution (Na_2SiO_3) and sodium hydroxide (NaOH) pellets with a purity of 99% has been prepared beforehand. The NaOH pellets were obtained from Merck (Germany) and the Na_2SiO_3 solution (SiO_2 = 12%, Na_2O = 30%) from PC Laboratory Reagent.

2.2. Geopolymer and Portland cement concrete preparation

The OPC was prepared by dry mixing of fine and coarse aggregate together with cement for 2 min by a concrete drum mixer with the capacity of 0.3 m^3, to make a uniform particle distribution in dry stage. The coarse to fine aggregate ratio was kept at 1.5 for all the specimens. 10 more minutes of mixing with the addition of water to keep the water-binder ratio to 0.26. MASTERGLENIUM ACE 8388 (GLENIUM ACE 388RM) superplasticizer was used at 0.02 wt% of the binder to provide the workable mix. The concrete layer was poured into the molds immediately after the mixing and vibrated with a manual vibrator to remove the air bubbles and to fill the space between reinforcements. The thickness of the layer varied between 150, 125 and 100 mm. The half casted beam was cured for 24 h in ambient condition with an average temperature and humidity of 28 °C and 70%, respectively.

The alkali activator solution was prepared by mixing 16 M NaOH with Na_2SiO_3 solution with Na_2SiO_3 to NaOH ratio of 2.5. The activator to fly ash ratio was kept at 0.5 for all the specimens. First, dry sand, gravel and fly ash were mixed together for 2 min followed by addition of 0.15 wt% of the binder, tap water and mixing for next 3 min. Alkali activator was gradually added to the mixture and mixed for another 5 min. The GPC was immediately poured into the molds and compacted to make sure it is passed through the reinforcements and reduced the vacant space and