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The engineering properties and microstructure development of cement mortar containing high volume of inter-grinded GGBS and PFA cured at ambient temperature

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HIGHLIGHTS

- Highest mechanical strength is formed by 40% geopolymer and 60% cement.
- Cement gain strength rapidly, geopolymer gain strength continuously.
- Geopolymer shows similar or better performance compared to cement in long term.
- 10% of cement in geopolymer mix will induce flast seeting during fabrication.
- A refined microstructure is formed by hybrid between geopolymer and cement paste matrix.

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ABSTRACT

The high consumption of Portland cement in concrete production had contributed to a significant carbon dioxide emission to the environment. The application aluminosilicate rich waste material in the manufacturing of Portland cement as partial replacement material has become an alternative to minimize the carbon dioxide emission and at the same time to solve waste management problems through recycling of industrial waste material. The study is mainly aimed to maximize the level of cement replacement of ground granulated blast furnace slag (GGBS) and pulverized fuel ash (PFA) in the production of cement mortar through hybridization and mechanical activation. The laboratory testing program includes bulk density test, compressive strength test, flexural strength test, ultrasonic pulse velocity test (UPV) and dynamic modulus test from 7 days of curing age up to 90 days. Besides, scanning electronic microscopy (SEM) and energy-dispersive X-ray spectroscopy test (EDX) have been performed in order to determine the microstructure development of the paste sample. It is observed that the inter-grinding activation method is able to further enhance the reactivity of the geopolymer material from the aspect of increase in mechanical strength and improve in durability performance.

1. Introduction

The rapid development of construction industry causes a drastic increment of demand for Portland cement as it is extensively used as binder material in the production of concrete [1]. However, the production of cement results in the emission of large amount of carbon dioxide into the atmosphere. According to Joseph Davidovits's research in 1994, every ton of cement production will release approximately 1 ton of carbon dioxide and this significant amount of carbon dioxide emission contributes to about 5% of total man-made carbon dioxide emission [2]. Thus, the utilization of supplementary cementitious material as a partial cement replacement material has become an alternative to develop a low carbon footprint binder system which has a relatively lower embodied energy of production than conventional Portland cement binder [3–6]. The supplementary binder materials such as ground granulated blast furnace slag (GGBS) and pulverized fuel ash (PFA) are rich in silica and alumina [7,8]. GGBS is an industrial by-product from the production of steel. During the processing of iron oxides to metallic iron in a blast furnace, the rapid quenching of blast furnace slag forms glassy calcium-magnesium aluminosilicate granules which can be further grinded to form a fine powder [9]. It is often used in combination with ordinary Portland cement as a supplementary cementitious material to reduce cost and carbon

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dioxide emission while at the same time enhance the mechanical strength and durability performance of concrete material [10]. The silica and alumina compounds from the materials will dissolved during mixing with water and undergo geopolymerization to form a three-dimensional amorphous aluminosilicate network with strength similar or higher than conventional hardened tobermorite matrix of ordinary Portland cement [9]. However, conventional geopolymer concrete require high dosage of chemical activator (30%–65% by total weight of binder) which led to handling problem and significant increase in manufacturing cost of the material [8,11,12]. The typical concentration of alkali activator solution ranges between 6 and 18 M which is used for dissolution of aluminosilicate species from geopolymer material like GGBS and PFA to promote the polycondensation and strength development of geopolymer concrete [13,14]. Besides, elevated temperature treatment (>60 °C) during post fabrication of the concrete is required to achieve mechanical strength suitable for structural applications. This treatment creates severe challenges to the large scale production of the geopolymer concrete as it will consume large amount of energy and comparatively uneconomical as compared to the ambient temperature cured ordinary Portland cement concrete and mortar [15].

Hence, it is the primary aim of the study to maximize the low carbon footprint benefit of geopolymer material as primary binder system in concrete without inducing other subsequent problems as aforementioned. This is done through, mechanical activation of aluminosilicate rich geopolymeric source materials such as GGBS and PFA followed by subsequent blending with Portland cement at high cement replacement level. Through mechanical activation, the particles size GGBS and PFA has been reduced and it is known that the particle below 45 μm tend to improve mechanical strength of geopolymer concrete [16–19]. Moreover, the utilization of mechanically activated PFA as a supplementary cementitious material is also well discussed for a similar application such as for the enhancing the adsorptive properties of concrete, stabilization/solidification of hazardous industrial waste and improvement of thermal stability of PFA for metal matrix nano-composites production [20–30].

There are a number of studies [31] which are related to the mechanical activation of aluminosilicate rich material for the purpose of improved activity index with cement. However, the literatures related to the application of mechanically activated PFA and GGBS hybrid supplementary binder is relatively scarce. Hence, the main objective of this study is to develop the material design and method for stabilizing GGBS and PFA for use as the primary binder for making cementitious composites with the utilization of Portland limestone cement as the source of alkali activator instead of corrosive alkali metallic hydroxides. The mechanical strength, durability performance, dimensional stability, and microstructure development of inter-grinded GGBS and PFA mortar was also examined.

2. Material and method

2.1. Material

2.1.1. Binder material

In this study, the GGBS used is sourced locally from a milling plant in Amanjaya, state of Kedah. The result of Blaine fineness analysis indicated that the GGBS used had a specific surface area of 4012 cm^2/g. The specific gravity of GGBS was determined to be 2.86 and X-ray diffraction pattern of the material is shown in Fig. 1. Further analysis on the amorphous hump at 2Θ scale between 22° and 38° in accordance to guidelines in BS EN 15167-1 was indicative that the total glass content of the material is 91%. Hence, crystalline mineral phases were present in minor compositions. Among the crystalline phases detected within the materials were gypsum, anhydrite and hatrurite.

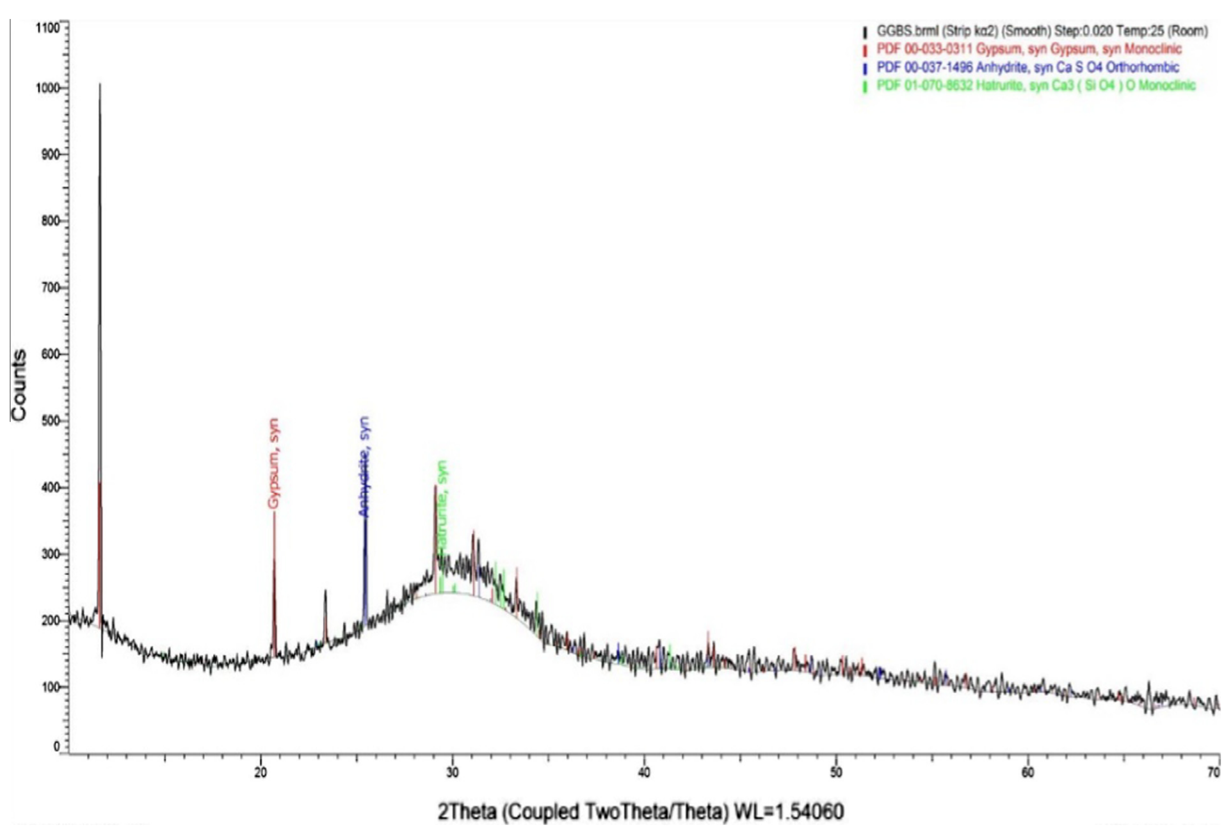

Fig. 1. XRD patterns of GGBS.