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Review

An overview on rheology, mechanical properties and durability of high-volume slag used as a cement replacement in paste, mortar and concrete

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HIGHLIGHTS

- HVS increased workability, setting time, fracture energy and toughness.
- HVS decreased mechanical strength especially at early ages and carbonation resistance.
- HVS decreased permeability, water absorption, chloride ion penetration and pH value.
- HVS increased corrosion resistance, chemical resistance and electrical resistivity.
- Suitable curing, nano particles and other materials can improve HVS matrix strength.

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ABSTRACT

Disposal of slag resulting from pig iron process is one of the main eco-friendly confrontations. This confrontation is still increasing with the increase slag content and diminishing the landfill space latitude. Accordingly, studies have been achieved to reuse granulated ground blast-furnace slag (denoted as slag) by way of high-volume (HVS) as a cement replacement in building materials. This article offerings a review summary of the earlier investigations which concentrated on using HVS (≥45%) as a part of cement in conventional paste, mortar and concrete mixtures. Fresh properties, mechanical properties, durability and other properties of paste, mortar and concrete mixtures containing HVS as a cement replacement have been reviewed. Furthermore, curing conditions as well as different additives used to improve some properties of HVS system such as nano particles, cementitious materials, and other materials have been summarized.

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1. Introduction

The production and demand of cement in the world are increasing from day to day. In 2009, the total cement production in the world may exceed three billion tonnes [1], whilst in 2012 and 2015 the total production of cement reached approximately 3.6 and 4.18 billion tonnes, respectively [2,3]. The production of PC is increasing dramatically in developing countries. It is predicted that by 2020, the cement demand could increase by approximately 115–180% in comparison with 1990s. This may reach 400% by 2050 [4] or 200% by 2050 compared to 2010s [5]. This is peculiarly thoughtful in the present situation of variation of climate initiated by CO_2 releases worldwide, resulting in occurrence of natural disasters, an increase in seawater level etc [6]. Production of cement not only causes a problem to the environmental, but also absorbs extensive amounts of virgin materials. Manufacturing one tonne of cement needs around one and half tonnes of virgin materials [7]. In addition, the production of cement needs huge energy [8]. One of the trials to produce more ecofriendly paste/mortar/concrete is to substitute a specific content of PC with waste or by-product materials such as slag and fly ash (FA) with high volume [9] to decrease environmental impact and enhance economic benefits.

Iron blast-furnace slag is shaped in the manner of pig iron resulting from coke combustion residue of coke, iron ore. The temperature of the molten slag is almost similar to that of the iron (1400–1600 °C). The slag is tapped off after rising to the surface. The alumino silicates of calcium and silicates are the main chemical components of Blast-furnace slag [10]. After quick cold, the formation of glassy granular material has been formed [11]. By quick cooling, the molten blast-furnace slag can be converted to fine particles with size <4 mm with less crystallization [12]. If water quenching slag exposed to a suitable grinding, it will act as a pozzolanic material as well as PC, but with latent hydration [13].

It is estimated that the worldwide of iron slag production around 300–360 million tonnes [3]. Attributable to the fast economic progress and the development in the world iron production, slag has significantly increased. The huge amounts of this slag are still landfills disposed [14]. Therefore, slag would not only be scraped off to avoid pollution of the environmental, but would be re-used as an invaluable material. Employing slag instead of throwing it off as a by-product material could be recycled as a part of building material. One choice to eliminate the slag disposal in a friendly way is to re-use it as a building material after reasonable grinding. A remarkable portion of slag is applied as an aggregate source. Using slag as an aggregate for concrete is well-known from several years ago. Another part is ground and blended with PC. Since 1900s, the ground slag was used as a cementitious material in concrete [15]. Although grinding slag needs energy, this energy is still lower than that required for PC production by approximately 90% [16]. The blending quantity of slag is 25–30% in normal cement [17]. Also replacement rates for slag vary from 30% up to 85% are available, but 50% is usually used in most applications [18]. The use of slag as a building material can save energy, reduce emission of carbon dioxide and conserve natural resources. Although slag is an invaluable admixture for blended cement, only little quantity of the total existing slag is re-used for this purpose. As a result, the method to replace cement with high-volume of slag has generated considerable interest.

HVS is a methodology to increase the slag input in a matrix (paste/mortar/concrete). However, HVS has been not a unified definition yet now. Some authors [19,20] believed that partially substituting cement with 20% slag and above, by weight, can be used as a HVS. Shafigh et al. [21] used slag levels of 30% and higher as partially replacement of cement, by weight, as a HVS. Sobolev [22] believed that partially substituting cement with 45% slag, by weight, can be used as a HVS. Some authors [23,24] used 50% slag as partially replacement of cement, by weight, as a HVS. Parniani et al. [25] used 50% and 70% of slag as partially cement replacement, by weight, into concretes as a HVS. Sivasundaram and Malhotra [26] used 50–75% slag as partially cement replacement, by weight, into concretes as a HVS.

In general, the research of using of slag with high-volume in any matrix hasn't been extensive similar to high-volume fly ash (HVFA) in that matrix. Not amazingly, the presentation of HVS paste/mortar/concrete in the field is too restricted and classically only applied to get special characteristics in concrete. On the same line, there are many prior studies attributed to the influence of various slag replacement levels up to 60% on the properties of concrete [27]. On the other hand, too finite studies have been accompanied on using slag at high substitution levels (>60%). Thus, the literature still needs further studies related to the influence of a HVS, up to 100%, on the properties of paste/mortar/concrete.