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Modeling of the compressive strength and UPV of alkali-activated slag pastes

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Abstract

Alkali cementation material is a recently developed type of environmentally friendly and economical material that is produced from industrial waste (e.g., fly ash and slag). This study used different liquid-solid ratios and alkaline solutions as well as slag to produce pastes. Three liquid-solid ratios (L/S of 0.50, 0.55 and 0.60) and three alkali agent contents (N of 0.5%, 0.75% and 1.0%) are used in mixed proportions. The compressive strength and ultrasonic pulse velocity (UPV) are tested at the ages of 3, 7 and 28 days. The results show that the compressive strength and UPV increase with increasing alkali agent content and with age but decrease as the liquid-solid ratio increases. The compressive strengths and UPVs for various alkali agent contents increase by 1.52-12.10 and 1.06-1.84 times, respectively, during aging from day 3 to day 28. In addition, the prediction models of the compressive strength and UPV of alkali-activated slag paste with alkali agent content are deduced in this study. Another prediction model of the compressive strength function of UPV is also proposed. According to the comparisons between the predicted values and the test results, the MAPE values of compressive strength and UPV are only 0.003-0.031% and 0.023-0.050%, respectively. The MAPE values are much lower than 10%. In addition, the MAPE values of the compressive strength (calculated by Eq. (16)) that were evaluated based on the UPV test results are 7.37-14.31%, and the average of the MAPE values from all the test results is approximately 10.47%, which is only slightly higher than 10%. Thus, the proposed analysis models achieve satisfactory forecasting accuracy for the alkali-activated slag paste.

Keywords: Paste, slag, alkali-activated, prediction model.

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1. Introduction

Due to the rapid industrial development in this century, overexploitation causes severe environmental damage and aggravates the greenhouse. Thus, it is an important environmental objective worldwide to reduce the atmospheric CO_2 concentration of greenhouse gases (Chen *et al.*, 2010; Torres-Carrasco *et al.*, 2015). Therefore, in an environment with limited resources, waste recycling has become a new major topic in environmental protection and sustainable development in recent years (Australian Government, 2012; Bolden *et al.*, 2013; Martinez-Barrera *et al.*, 2016). Civil engineering and building construction are closely related to human life and cement is one of the most frequently used materials for civil engineering and building construction. Since 2006 and due to population growth and the global demand for concrete as the main building material for construction, cement production expected to increase each year by between 0.8-1.2% to 3.7- 4.4 billion tons in 2050. As a result of this significant growth in cement production, CO_2 emissions will also rapidly increase (Torres-Carrasco *et al.*, 2015). While traditional design and evaluation approaches are based on the principle of maximizing economic efficiency and consider quality, cost, and time, the new approach of 'sustainable construction' emphasizes the importance of reducing the environmental impact of buildings and infra-structures (Yang *et al.*, 2015). However, cement production results in substantial emission of CO_2 and the total CO_2 emissions from the global cement manufacturing industry account for 5-7% of global total greenhouse gas emissions (Chen *et al.*, 2010). To reduce the environmental impact, cement consumption must be reduced.

In concrete production, several techniques have been introduced for reducing CO_2 emissions. The techniques include the capture and storage of CO_2 emissions and the reduction of the amount of clinker by replacing it with supplementary cementitious materials that are obtained from by-products such as fly ash and ground granulated blast-furnace slag (Yang *et al.*, 2013). The use of alkali-activated binder has gradually attracted attention as another active effort to reduce CO_2 emissions in concrete production (Duxson *et al.*, 2007; Pacheco-Torgal, 2008). In recent years, alkali-activated inorganic polymer materials have become a developing trend. Alkali cementation uses an alkaline agent and industrial by-products, such as slag and fly ash, for activation, such that satisfactory economic benefits and engineering properties are obtained, and can be used as a green energy material to replace cement (Aydin and Baradan, 2014; Abdalqader *et al.*, 2015; Gu *et al.*, 2015; Abdalqader *et al.*, 2016; Ding *et al.*, 2016; Ellis *et al.*, 2016; Kim *et al.*, 2017). The alkali-activated inorganic polymer has not only high strength and workability but also excellent fire resistance, thermal insulation and corrosion resistance. Alkali cementitious materials are a new type of environmentally friendly and economical materials that are produced from industrial waste (e.g., fly ash and slag). They possess many excellent engineering properties, including high compressive strength, light weight and low thermal conductivity (Wang *et al.*, 2014; Wang *et al.*, 2015).

Fly ash (FA) and ground granulated blast furnace slag (GGBFS) are the most frequently used raw materials in the production of alkali-activated binders. Aydin and Baradan (2014) reported that the activation process of slag varies with the chemical properties and phase compositions of the slag and the type and concentration of activators. Slags have a variable composition that depends on the raw materials and the industrial process; hence, each slag responds differently to the activation process. For each slag, it is necessary to plan a research program for determining the