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The effects of cement/fly ash ratios on the volcanic slag aggregate lightweight concrete masonry units

S. Demirdag *, I. Ugur, S. Sarac

Mining Engineering Department, Suleyman Demirel University, 32260 Isparta, Turkey

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Abstract

Masonry is one of the oldest construction materials, which was used for all kind of building applications especially for sufficient compressive strength in combination with good acoustic and thermal properties with low construction costs and solving some durability problems. The production of lightweight masonry block is generally performed by using a highly mechanised industry based on great automation and accuracy which is different from the other concrete types. This production has to match strict standards that describe properties specified for the products. Volcanic slag lightweight blocks (VSLB) are made of volcanic slag, cement and water, which are used in construction of non-load bearing infill walls and slabs. One of the most effective ways to reduce the dead load in a multi storey building is to lighten the weight of the structure. Therefore, natural lightweight aggregates, especially produced from the volcanic slag can be considered as a lightweight concrete aggregate in construction of buildings.

In this research, control lightweight concrete (CLC) mixtures containing volcanic slag aggregates (VSA) with only normal portland cement (NPC) and finally with fly ash lightweight concrete (FALC) mixture containing 20% of FA as a replacement of the cement by volume were prepared and tested. In addition, no-fines aggregate was prepared from which the fine aggregate component of the matrix under 1 mm was entirely omitted and no-fines aggregate mixtures with NPC and FALC were compared with CLC and the effect of FA on the strength and unit volume weight was analysed.

VSA samples were obtained from the quarries near Manisa City, Aegean Region of Turkey and after some crushing processes; samples were classified into specialized size fractions (0–4 mm as fine aggregates (FVSA), 4–8 mm as coarse aggregates (CVSA) and 1–4 mm no fines aggregates). From those aggregates, several cubic samples were prepared by using different ratios of size fractions (60% fine and 40% coarse) including 5%, 8%, 10% cement by volume. FALC mixture containing 20% of FA as a replacement of the cement was prepared for analysing the unit weight and compressive strength results with demanding criterions of current standards. The research showed that, masonry units having desired properties can be produced by using fine and coarse VSA lightweight aggregate in the mixture with 10% cement by volume.

Keywords: Volcanic slag; Fly ash; Lightweight aggregate concrete; Masonry; Compressive strength

1. Introduction

Lightweight concrete is of utmost importance to the construction industry and is used in civil engineering field, as filler or for the manufacture of heat and sound insulating elements such as panels, partitions as well as load bearing structural elements [1]. Lightweight concrete is generally used for reducing the dead weight of a structure as well as to reduce the risk of earthquake damages to a structure because the earthquake forces that will influence the civil engineering structures and buildings are proportional to the mass of those structures and buildings [2,3]. Lightweight aggregate concrete (LWAC) has been successfully used and investigated for structural purposes for many years due to a lot of advantages including higher

* Corresponding author. Tel.: +90 246 2111308; fax: +90 246 2370859.
E-mail address: demirdag@mmf.sdu.edu.tr (S. Demirdag).

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strength to weight ratio, better tensile strain capacity, lower coefficient of thermal expansion, and superior heat and sound insulation characteristic due to air voids in the lightweight aggregate. Due to inner voids, the lightweight aggregates can easily absorb water and float during the mixing of the cement paste, which deteriorates the workability of the mixture and the strength of lightweight concrete [4].

One of the components that can be used in masonry units is the lightweight concrete block [5]. Lightweight concrete blocks are cement based building materials known as compressed and stabilized block (CSB) originally promoted as having an indefinitely long service life, and require only minimum maintenance [6]. The intended function of a CSB is as an internal and external walling unit. The primary desirable characteristics of walling units are strength, dimensional stability and resistance to weathering [6]. These properties are to a large extent governed by the choice of constituent materials, and by the quality of the manufacturing process used in their production [7].

Volcanic slag is a natural vesicular glassy lava rock transformed with open pit mining for an industrial material. For nearly three centuries volcanic slag has been used successfully around the world in more than 70 different types of applications [8,9]. Crushed and screened into specified sizes, the open structure and excellent drainage properties of this material create a truly versatile product for both landscaping purposes and as a bedding material for under soil drainage applications. The most notable usage areas of lightweight masonry blocks are in the form of CSB on high-rise buildings, pre-cast and pre-stressed concrete elements, ground cover, pathways, hydroponics growing medium, dry or desert garden material, bedding material for drainage pipes asphalt road surfaces, soil conditioner and geotechnical fills [10]. In addition, it offers superior fire resistance, effective sound absorption, good seismic performance, low shrinkage and high strain capacity [11].

Volcanic slag is a lightweight aggregate and is the basaltic equivalent of volcanic materials; therefore it is also called as basalt lava. It is sometimes called cinders or volcanic cinder [9,12]. It is rich in highly vesicles volcanic glass which gives it high porosity and low density [13]. It forms when blobs of gas-charged lava are thrown into the air during an eruption and cool in flight, falling as dark volcanic rock containing cavities crated by trapped gas bubbles [14]. Volcanic slag materials are typically reddish to black in colour, mostly due to its high iron content. The surface of some volcanic slag may have a dark green iridescent colour; oxidation may lead to a deep reddish-brown colour.

In this research, the fly ash of Soma thermal power station was added to the VSA concrete mixture as a mineral admixture to determine the strength properties and unit volume weights of the samples. The effects of different cement and fly ash ratios on engineering properties of the CSB were investigated.

2. Experimental scope

2.1. Materials used in the research

Normal Portland cement (NPC) which is comparable to ASTM Type I (32.5 MPa) was used throughout this research. The chemical composition and physical properties of the cement used in this research are given in Tables 1 and 2.

The C class Fly Ash (FA) was supplied from the electricity-generating Soma Thermal Power Plants. FA being the most common pozzolanic material encountered in construction is a by-product of coal burning power plants. The FA is disposed of either by sluicing to ponds or hauling to solid waste disposal areas. Disposal operations are quite expensive and require the use of land that could be used for other purposes [15]. Soma (in Manisa, Turkey) thermal power plants annually produce 1,312,000 tons of FA as a waste by-product respectively, only 1% of Soma FA is productively employed, the rest is disposed of in landfills at great expense [15]. Its chemical composition is given in Table 1. Its specific gravity is 2.45 g/cm^3, blaine specific surface area is 3750 cm^2/g. FA particles have various shapes such as sphere, agglomerate and angular, some of which are the hollow particles known as cenospheres [16]. FA was widely applied in different industrial sectors in Turkey such as cement production, different types of concretes, aggregate, adobe, brick, aerated concrete, insulation material, dam and road construction [17].

Volcanic slag aggregate (VSA) used in this experimental research was supplied from the quarry in near Manisa City, Aegean Region of Turkey. The quarry contains volcanic slag aggregate in reddish colour. All aggregates obtained from the quarries were first crushed by a primer crusher.

Table 1
Chemical composition of cement, fly ash and volcanic slag aggregate

Major element	Cement (%)	FA (%)	VSA (%)
SiO_2	25.02	45.08	45.8
Al_2O_3	5.97	22.94	16.3
Fe_2O_3	3.26	4.72	8.7
CaO	48.99	17.16	9.2
Na_2O	2.45	1.36	3.4
K_2O	4.16	0.33	0.5
MgO	1.60	1.56	4.5
LOI	5.79	1.41	1.43

Table 2
Mechanical and physical properties of cement

Specific gravity (g/cm^3)	2.91
Blaine specific surface (cm^2/g)	3825
Initial setting time (min)	177
Final setting time (min)	258
Volume expansion (mm)	1
Compressive strength (MPa)	
2 days	14.05
7 days	26
28 days	38.8