Construction and Building Materials 124 (2016) 816–825

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Investigation about the effect of different fine aggregates on physical, mechanical and thermal properties of mortars

Niyazi Ugur Kockal

Akdeniz University, Department of Civil Engineering, 07058 Antalya, Turkey

HIGHLIGHTS

- The lightweight aggregates absorbed more water than normal weight aggregate.
- Compressive and tensile strength decreased with the incorporation of lightweight aggregates.
- Mortar with slag aggregate revealed the lowest indirect tensile strength.
- The lowest thermal conductivity values were obtained by slag aggregate mortars.

ARTICLE INFO

Article history:
Received 20 January 2016
Received in revised form 11 July 2016
Accepted 3 August 2016

Keywords:
Lightweight fine aggregate
Mortar
Strength
Thermal properties

ABSTRACT

Energy saving is the most important parameter for energy efficiency. To use energy efficiently without any reduction in production, comfort and work power; energy saving is needed. Energy efficiency of buildings is primarily necessary in order to save costs and also reduce the amount of CO_2 emission and greenhouse gases in the atmosphere. In recent years, thermal insulation with different originated materials has been studied. In order to maximize energy saving, more attention should be paid for the selection of appropriate construction materials which can be utilised for insulation. In this experimental study, cement mortars with different fine aggregates were prepared and compared by means of physical, mechanical and thermal properties. The results showed that acidic pumice aggregate mortar had higher capillar absorption and lower thermal conductivity than the basic pumice aggregate mortar. It is also found that mortars with porous slag had the lowest strength values and the highest permeability. However, they exhibited the best performance among other mortars in thermal properties.

1. Introduction

Buildings are responsible for 33% of all energy-related CO_2 emissions worldwide [1]. Buildings consume the energy of at least 40% and one third of global greenhouse gas emissions in most countries [2,3]. By improving the energy efficiency of buildings, energy consumption and CO_2 emission can be reduced by almost 6% in the EU (European Union) [4]. The consumption of energy for the purpose of heating and cooling in the construction sector is almost half of the total energy consumption. Reduction of energy resources and deterioration of ecological balance in the world prompt humanity to protect and use existing resources more efficiently. There are many researches on the variation of thermal properties of numerous materials. The number of these studies has further increased especially in recent years.

Some researchers pronounced below attempted to decrease the thermal conductivity of cementitious mixtures by conducting studies on cement as an ingredient. Cement with high thermal conductivity and specific heat was manufactured by adding silane and silica fume [5]. One of the additives, silane contributed to increase in both specific heat and thermal conductivity, whereas silica fume addition increased the specific heat while decreased the thermal conductivity. The effects were mainly attributed to the large area of the interface between silica fume and cement matrix and the contribution of the interface to decreasing the thermal conductivity and increasing the specific heat [6]. Addition of high-volume fly ash reduced the thermal conductivity of mortars and concretes [7]. Little difference in specific heat capacity was observed for mortars and concretes produced by replacing cement with fly ash because the specific heat capacities of the fly ash and cement were quite similar which were measured as 0.74 and 0.73 J/(g K), respectively.

On the other hand, some of the investigations of researchers cited below have sought way to reduce the values of thermal

E-mail address: ukockal@yahoo.com

http://dx.doi.org/10.1016/j.conbuildmat.2016.08.008
0950-0618/

conductivity by adding fibers or replacing aggregates. Formation of microstructure played an important role in determining the mechanical and thermal properties of lightweight foamed concrete [8]. Lime as aggregate replacement did not contribute much on mechanical but good in thermal properties. The presence of polypropylene fibers did not contribute to strength development at higher density but gave good result in compressive strength for low density. The burnt clay brick-chips used as coarse aggregate showed greater specific heat than the stone-chips concrete [9]. Thermal diffusivity increased with increasing density. Thermal conductivity of both types of concrete was directly proportional to its diffusivity. The effect of pumice aggregates on strength and thermal properties were also studied in some investigations [10–12]. In such studies, despite the researchers reduced the thermal conductivity coefficient at a certain level by changing fine and coarse pumice aggregate-cement ratio, they could not avoid decrease in strength. In another study, the researchers studied the potential use of foamed concrete in thermal insulation and they indicated that thermal insulation performance was improved by addition of natural fibers [13]. Another researcher tested the specimens produced with pumice, sand, cement and nut shell in varying proportions and found that increase in the nut shell ratio decreased the thermal conductivity in any case [14].

Therefore, this study aims to evaluate how natural and by-product materials affect the thermal properties and some other characteristics of cement mortar using different aggregate types, with a constant cement dosage and water to cement ratio. In order to determine the physical, mechanical and permeability properties of mortars, the bulk density, water absorption, porosity, compressive, flexural and splitting tensile strength, capillary water absorption and thermal conductivity tests were conducted. The findings of experimental study performed on the materials for the determination of physical, mechanical, durability and thermal properties are compared and discussed.

2. Materials and method

2.1. Constituents of mortars and determination of their properties

Cement used in the mixtures was CEM II/A-M (P-L) 42,5 N complying with TS EN 197-1 [15] with a specific gravity of 3.04 and a specific surface of 350 m^2/kg. The selection of this cement type was due to its lower thermal conductivity compared to Ordinary Portland cement. For mortars, the greatest reduction in thermal conductivity was achieved by adding pozzolanic materials into the ordinary Portland cement [7]. Initial and final setting times of cement were 181 and 298 min, respectively.

Fine aggregates utilized in the study were natural crushed calcareous (limestone) sand (CS) from Antalya, porous slag (SS) from Antalya Eti Ferrochrom Factory, acidic pumice (AS) from Isparta and basic pumice (BS) also known as scoria from Manisa.

The chemical composition of the cement and aggregates are given in Table 1. Pumices show acidic and basic properties and are named as acidic pumice and scoria (basic pumice), depending on the SiO_2 content [16–18]. SiO_2 being the major chemical component, AS can be called as intermediate acid due to possessing 54.77% SiO_2 which falls in the 52–66 wt% SiO_2 and BS can be named as basic pumice due to having 47% SiO_2 which remains in the range of 45–52 wt% SiO_2. SiO_2, Al_2O_3, CaO and Fe_2O_3 constitute major contents of the lightweight aggregates. In addition, $SiO_2 + Al_2O_3 + Fe_2O_3$ content of pumice aggregates is greater than 70%, and CaO content is less than 10%. Also, slag has a higher CaO content than the other lightweight aggregates.

X-ray diffraction (XRD) with Cu Kα radiation was used to identify the mineral phases in lightweight fine aggregates (Fig. 1). According to XRD results, common mineral phase present in slag is Merwinite ($Ca_3Mg(SiO_4)_2$). Anorthoclase ((Na, K)$AlSi_3O_8$) is the main crystalline phase in the basic pumice whereas Orthoclase ($KAlSi_3O_8$) is detected as the major mineral phase in the XRD of acidic pumice.

Sieve analysis of aggregates was carried out according to ASTM C 136 [19] and grading of aggregates conformed to the requirements given in ASTM C 33 [20]. Fig. 2 exhibits the particle size distribution curves of aggregates used. It is apparent that slag was the coarsest aggregate with a fineness modulus of 4.28 compared to other aggregates followed by calcareous, basic and acidic pumice aggregates whose fineness modulus values were 4.22, 3.44 and 3.40, respectively. Median particle sizes of CS, AS, BS and SS were 1.28, 0.57, 0.64 and 1.06 mm, respectively.

Chemical admixture used for providing consistency of mortars constant (flow diameter 20 ± 1 cm) was a modified lignin sulphonate based water reducing/plasticizer admixture with specific gravity of 1.20 consistent with TS EN 934-2 [21].

Chemical composition of cement and aggregates was found by X-ray fluorescence (XRF) analysis. Specific gravity and water absorption of fine aggregates were determined according to ASTM C 128 [22]. Aggregates were tested in oven-dry condition utilizing the shoveling and rodding procedure to determine the unit weight (loose and rodded) and void content according to ASTM C 29 [23].

2.2. Preparation of mortars and determination procedure of their properties

Lightweight aggregates were completely replaced with natural limestone sand. All substitutions were made in volume. All sample preparations were processed in a similar manner, according to TS EN 196-1 [24]. Initial trial mixes were prepared to provide suitable fresh and hardened properties such as consistency, cohesiveness, strength. As a result, water-cement ratio and cement dosage of the mixtures were adopted as 0.57 and 480 kg/m^3, respectively.

The consistency test was performed according to ASTM C 270 [25]. The mortars were cast into steel moulds and kept for 24 h. The hardened mortar specimens were then demoulded and maintained under lime-saturated water at 20 ± 2 °C until 27 days.

The bulk density, water absorption and porosity values were obtained by testing 40 × 40 × 160 mm prism specimens according to ASTM C 642 [26] by using the following equations:

$$A = W_1/(W_2 - W_3) \quad (1)$$

Table 1
Chemical composition of constituents (%).

Constituents	LOI[a]	Na_2O	MgO	Al_2O_3	SiO_2	SO_3	K_2O	CaO	Fe_2O_3
Cement	5.81	1.25	2.33	6.38	21.77	1.32	1.06	56.66	2.68
CS	40.81	0.08	1.02	0.64	3.94	–	–	54.01	0.11
BS	2.32	4.62	4.39	17.95	47.00	0.16	3.46	7.31	10.52
AS	2.75	3.95	2.46	15.46	54.77	0.21	5.25	5.36	7.08
SS	3.66	0.05	14.71	11.75	31.13	0.06	0.05	36.7	0.28

[a] Loss on ignition.