Construction and Building Materials 101 (2015) 260–267

Contents lists available at ScienceDirect

Construction and Building Materials

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

A comparison of strength and elastic properties between conventional and lightweight structural concretes designed with expanded clay aggregates

Murat Emre Dilli, Hakan Nuri Atahan *, Cengiz Şengül

Istanbul Technical University, Civil Engineering Faculty, 34469 Maslak, Istanbul, Turkey

HIGHLIGHTS

- Mechanical and elastic properties of LWAC's has been investigated.
- Compressive strength values up to 68 MPa has been reached for LWAC mixtures.
- Effect of internal curing on the strength development of LWAC's is significant.
- A new prediction model for the estimation of MOE of LWAC mixtures has been proposed.
- LWAC mixtures have shown more brittle behavior compared to CC mixtures.

ARTICLE INFO

Article history:
Received 30 April 2015
Received in revised form 26 August 2015
Accepted 15 October 2015

Keywords:
Lightweight aggregate concrete (LWAC)
Conventional concrete (CC)
Expanded clay (EC) aggregate
Elastic modulus (MOE)
Poisson's ratio
Strength
Ductility
Unit weight

ABSTRACT

Properties such as compressive strength, modulus of elasticity (MOE), Poisson's ratio and the ductility of lightweight aggregate concrete (LWAC) mixtures were investigated, and the results obtained were compared with conventional concrete (CC) mixtures with similar design characteristics. For this purpose, LWAC mixtures were casted using lightweight expanded clay (EC) aggregates with different unit weight properties. Dry unit weights of LWAC mixtures changed approximately between 1640 kg/m^3 and 2050 kg/m^3. To express the effect of matrix strength on the determined properties, concrete mixtures with different matrix strengths were designed by keeping the total aggregate volume constant. For this purpose, the water to cementitious material ratio and the amount of cementitious materials were changed. Results have shown that, depending on the unit weight of concrete, the compressive strength of LWAC mixtures varied between 20 MPa and 70 MPa. Compared with CC mixtures, the elastic properties and ductility of LWAC mixtures changed significantly. Within the same compressive strength range, LWAC mixtures showed remarkable reduction in MOE and more brittle behavior compared with CC mixtures. Poisson's ratios of the LWAC and CC mixtures, on the other hand, produced similar values. A new model for predicting the MOE of such concretes is also suggested.

1. Introduction

From the structural applications point of view, lightweight aggregate concrete (LWAC) mixtures have the advantages of being light with improved thermal and sound insulation properties. LWAC is a type of concrete in which lightweight aggregates are utilized, and it conforms to the criteria set forth in ASTM C 330 [1], which requires a minimum 28-day compressive strength of 17 MPa and dry density of 1120–1920 kg/m [2]. In addition to naturally occurring aggregates such as pumice aggregate, lightweight aggregates have better physical and mechanical characteristics. They can also be artificially produced using either natural raw materials or by-products [3]. Lightweight expanded clay (EC) aggregates are obtained by expanding natural clay in a 1200 °C rotary kiln [4].

Generally, considering the significance of aggregate-matrix interactions in conventional concrete (CC), the normal weight aggregate zone is stronger than the matrix and the interfacial transition zone (ITZ). However, in the case in which lightweight aggregates are introduced into a concrete mixture, they are the weakest constituents, which remarkably affects the elastic and mechanical properties of LWAC [5]. Research on aggregate properties and their influences on high-strength lightweight concretes showed that the

* Corresponding author.
E-mail address: atahanh@itu.edu.tr (H.N. Atahan).

http://dx.doi.org/10.1016/j.conbuildmat.2015.10.080
0950-0618/

weakest component in the mixture determines the strength of the concrete. Stresses are transferred through the aggregates and the mortar when the aggregates are the stiffest constituent of the concrete. However, if the aggregates are weaker compared with the concrete mortar phase, the stress transfer occurs through the matrix and cracks propagate through the lightweight aggregate particles. Hence, the lightweight aggregates are also weaker than the ITZ [6–8]. In LWAC, better hydration of the cement matrix can be reached by the internal curing effect. Given that the elastic and mechanical performances of LWAC are strictly related to the properties of the constituent materials, the density and volume factions of the lightweight aggregates allow the performance of LWAC to match that of normal weight concrete [9,10]. Various studies demonstrated that algebraic models are favorable to predict the modulus of elasticity (MOE) of concretes. In these models, the elastic properties of the aggregates and the matrix along with their volumetric ratios are the main basis of the calculated MOE [11]. In practical applications, however, it is more convenient to include variables in these models such as unit weight, compressive strength and the coefficients expressing the aggregate characteristics.

The present work experimentally investigated properties of LWAC mixtures such as the compressive strength, MOE, Poisson's ratio and the ductility in which the expanded clay aggregate were introduced. The results were compared with CC mixtures with the same matrix properties.

2. Experimental study

2.1. Materials and mixture properties

Mixture proportions and various design characteristics of conventional and lightweight aggregate concretes are given in Table 1. For the design of CC mixtures, natural sand (0–1 mm), limestone fines (0–5 mm) and crushed limestone (2–16 mm) were used as the fine and coarse aggregates. In the design of LWAC mixtures, on the other hand, some portion of the natural coarse aggregate, corresponding to a 4–8 mm size distribution, was replaced with expanded clay (EC) aggregate. For all mixtures, the maximum aggregate size was kept constant at 16 mm, and the mixed aggregate grading was also kept constant. Depending on the targeted unit weight of LWACs, two different types of EC aggregate were used with different density characteristics but approximately the same size distribution. The purpose for the selection of two different types of expanded clay aggregate was to obtain a wider range of unit weight and compressive strength values for LWAC mixtures. Moreover, the effect of aggregate strength characteristics on the compressive strength and elastic properties of LWAC's produced with these aggregates were also discussed. Some of the physical characteristics of natural limestone and two types of EC aggregates (EC1 and EC2) are given in Table 2. In order to estimate the strength characteristics of light weight expanded clay aggregates (EC1 and EC2), diametrical loading test has been performed on spherical shaped EC1 and EC2 samples [12]. For this test, individual EC1 and EC2 aggregates have been loaded to fracture (split) between two parallel steel plates and the maximum loads were recorded with a precision of 0.1 N. By this way, approximate tensile strength of individual aggregates has been determined using Eq. (1). In this equation P_{max} is the maximum crushing load (N), d is the diameter (mm) of expanded clay aggregates, and σ (MPa) is the approximate tensile strength of aggregates. For this test, 15 expanded clay samples has been tested for each of EC1 and EC2 aggregates. Average, maximum and minimum strength values along with standard deviations are given in Table 3.

$$\sigma \cong \frac{2.8 * P_{max}}{\pi * d^2} \quad (1)$$

Dry unit weights of the LWACs were targeted as approximately 1700 and 2000 kg/m^3, respectively, for LWAC-1 and LWAC-2 mixtures. To express the effect of matrix strength on the determined properties, however, concrete mixtures with different matrix strengths were designed while the total aggregate volume remained constant at approximately 60%. For this purpose, the water to cementitious material ratio and the amount of cementitious materials were changed. To eliminate the effect fly ash concentration in the total cementitious material, the ratio between the cement mass and the fly ash was also kept constant for all mixtures (Table 1). The water to cementitious material ratios for CC and LWAC mixtures were selected as 0.34, 0.42 and 0.50. In practice, this range of water to cementitious material ratio is being commonly used in concrete production.

An ordinary Portland cement (CEM I-42.5R) with a density of 3.14 was used in the mixtures. Both for CC and LWAC mixtures, an F type fly ash with a density of 2.54 was used as a supplementary material. For the desired mixture fresh properties, a naphthalene-based high range water reducer was used for both types of concretes, as necessary. Based on the water absorption values determined after 30 min of water soak, the EC aggregates were absorbed with the calculated amount of water before the concrete mixing process began. This way, especially for LWAC mixtures, the mixing water was prevented from being absorbed by the EC aggregates. It is clear from Table 2 that this adjustment was necessary for the mixtures containing lower density EC aggregates (EC 1). As seen in Table 2, the significant difference for 30 min. water absorption values between EC1 and EC2 aggregates is noteworthy. In order to explain this significant difference, optical microscope pictures of the cross sections of EC1 and EC2 aggregates were taken (Fig. 1). It can be seen from these figures that the micro structure of both outer layer and core of EC1 and EC2 aggregates are significantly different. Compared to EC1 aggregates, the outer layer of EC2 aggregates has significantly denser structure which delays the initial water absorption of these aggregates. Similarly, core structure of EC2 aggregates are much denser than core structures of EC1 aggregates. However, in terms of 24-h water absorption values, no significant difference was observed.

2.2. Tests performed

To determine the mechanical and elastic properties of the concretes produced, compression tests were applied on 100-mm diameter and 200-mm height cylinder specimens. Tests were completed on 28-day and 120-day old age samples, which were cured in lime-saturated water at 21 °C until the test ages. Because approximately 18% (by weight) of cementitious material consists of fly ash, 120-days of curing period was selected for better hydration of cementitious matrix. The MOE and Poisson's ratio values were determined from the strain values between 50 με to the stress of 40% of the compressive strength at the testing age [13]. The average dry unit weights of concretes, which are shown in Table 1, were determined using 100-mm diameter and 200-mm height cylinder specimens. Three samples from each mixture were dried in an oven until they reached a constant weight. In evaluating the relationships between the hardened properties and the unit weights of concretes, dry unit weights were taken into consideration.

Table 1
Mixture design properties of conventional and LWA concretes.

Mixture ID:	LWAC-1			LWAC-2			CC		
w/cm	0.34	0.42	0.50	0.34	0.42	0.50	0.34	0.42	0.50
Cement, kg/m^3	451	403	362	457	413	366	458	413	374
Fly ash, kg/m^3	100	89	80	101	92	81	102	92	83
Water, kg/m^3	188	207	221	190	212	224	190	212	228
HRWR, kg/m^3	6.0	0.8	–	3.8	0.7	–	6.5	2.4	–
Sand (0–1 mm), kg/m^3	419	416	414	425	426	419	426	427	427
Limestone fines (0–5 mm), kg/m^3	330	327	326	334	335	329	335	335	336
Coarse aggregate (2–16 mm), kg/m^3	131	129	129	132	133	130	895	896	897
EC Aggregate 1 (4–8 mm), kg/m^3	180	178	178	–	–	–	–	–	–
EC Aggregate 2 (4–8 mm), kg/m^3	–	–	–	462	464	456	–	–	–
Fresh unit weight, kg/m^3	1799	1749	1710	2101	2075	2005	2407	2375	2345
Average dry unit weight, kg/m^3	1750	1661	1638	2044	1975	1945	2352	2310	2273
Air, %	2.7	3.3	3.8	1.6	0.9	2.7	1.2	0.8	0.7
Slump, cm	15	15	15	18	18	17	17	17	16
Cement/Fly ash (by mass)	4.51	4.53	4.53	4.52	4.49	4.52	4.49	4.49	4.51
Aggregate volume fraction, %	0.627	0.627	0.628	0.623	0.620	0.625	0.622	0.619	0.619