Engineering Solid Mechanics 2 (2014) 201-208

Contents lists available at GrowingScience

Engineering Solid Mechanics

homepage: www.GrowingScience.com/esm

Experimental study on mechanical properties of different lightweight aggregate concretes

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ARTICLE INFO

Article history:
Received January 20, 2014
Received in Revised form
April, 10, 2014
Accepted 15 April 2014
Available online
17 April 2014

Keywords:
Lightweight aggregate concrete
Compressive strength
Mixture density
Cost per metric volume

ABSTRACT

Lightweight concrete is a suitable constructional material, which can decrease the weight of buildings and the hazards of earthquake loads. Hence, a large number of research studies have been focused on designing and manufacturing high strength lightweight concretes. In this research using the natural and industrial lightweight aggregates frequently found in the south-east region of Iran (Kerman province), high strength and low cost light weight concretes were manufactured. The effects of aggregate type, aggregate size, and concrete mixture were studied experimentally on the compressive strength of concretes and the density and cost of manufactured samples.

1. Introduction

Structural concretes including asphalt (i.e. bitumen or binder based) concrete, polymer (i.e. resin based) concrete and cement concretes are frequently used in many civil engineering applications such as roads, pavements and buildings and a large number of research studies have been performed in the past for investigating the performance and characterizing physical and mechanical properties of different types of concretes (Ibrahim et al., 2014; Soleymani Ashtiani et al., 2013; Aliha et al. 2012, 2014; Nabavi et al., 2013; Beigi et al., 2013; Paul & van Zijl, 2013; Hussain et al., 2014; Mills-Beale & You, 2010). One of the major problems and concerns in construction of big towers and skyscrapers is the dead load induced by the weight of roofs, floors and walls. The use of light weight concrete is a possible solution for decreasing such dead loads which will lead to economic benefits as well. While the density of ordinary cement concretes is typically about 2400 kg/m^3 the density of low weight concrete varies typically in the range of 300 and 850 kg/m^3. These materials can be divided to three main categories namely(i): light weight concrete, (ii) foamed concrete and (iii) concrete without fine

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doi: 10.5267/j.esm.2014.4.003

grain aggregates. Various lightweight aggregates such as natural pumice aggregates, heat treated natural raw materials like clay, slate or shale (Leca), industrial products like fly ash and slag and etc., are frequently used for producing lightweight aggregate concretes. Improved thermal and fire resistance properties, reduction in the dead loads, savings in transporting and handling precast units on site and reduction in the formwork and propping are some of the benefits of using lightweight aggregate concretes. A large number of experimental research works have been performed in the past for designing and manufacturing lightweight aggregate concretes. In the mentioned studies some physical and mechanical properties such as thermal expansion behavior at elevated temperatures (Uygunoğlu & Topçu, 2009), carbonation resistance (Gao et al., 2013), harsh environment effects (Thomas & Bremner, 2012), drying shrinkage (Kayali et al., 1999), tensile creep (Zhuang et al., 2013), microstructure (Andiç-Çakır & Hızal, 2012), durability (Heydari-rarani et al., 2014, Rossignolo & Agnesini, 2004), fire resistance (Go et al., 2012), fracture and crack growth resistance (Aliha & Ayatollahi, 2009; Aliha et al., 2012) and compressive strength and failure modes (Bogas & Gomes, 2013) of lightweight aggregates concretes have been studied. However, the compressive strength of these materials is the most important parameter for designing and manufacturing the lightweight aggregate concretes.

From the practical view point, the lightweight concretes are categorized into structural and non-structural concretes. In general the structural concretes should have 28days-compressive strengths of more than 160 kg/cm^2. Since the aggregate type has a main role in the strength properties of concretes, some researchers have investigated the influence of different natural and industrial aggregates including fly-ash (Lo et al., 2007, Wasserman & Bentur, 1997; Chi et al., 2003), pumice (Sari & Pasamehmetoglu, 2005; Libre et al., 2011), natural pozzolan (Mouli & Khelafi, 2008), organic lightweight aggregates (Cheng et al., 2012), waste materials (Mahmud et al., 2011), dredged silt (Wang et al., 2010) clay-blended sludge (Tay et al., 1991), slag (Thomas & Bremner, 2012), oil palm shell (Shafigh et al., 2010) and shale (Zhuang et al., 2013) on the mechanical properties of lightweight aggregate concretes. Other researchers like Kim et al. (2013), Wang and Tang (2012), Hassanpour et al. (2012) and Pan et al. (2011) studied experimentally the strength and mechanical behavior of other types of light weight concretes such as autoclaved aerated concrete, foamed concrete and fiber reinforced concretes. For those regions that are placed on the earthquake-prone areas (like Iran), the use of light weight structural materials is of great importance to decrease the risk of hazards during the earthquake. For example, the Kerman province (in the south east of Iran) is one of the hazardous regions for occurring earthquakes with magnitudes of more than 6 Richter scale (such as Bam earthquake with 6.6 Richter scale in 2003 which killed more than 50000 persons). Hence, the use of lightweight structural and constructional material is very important issue in these regions. The geological and field studies in the Kerman province have demonstrated that this region contains suitable mines for preparing lightweight aggregates for light weight concretes.

The aim of this paper is therefore, designing and manufacturing high strength light weight concretes using the aggregates frequently found in the Kerman province. The physical and strength properties of different aggregates and lightweight concretes are also determined experimentally and the cost per metric volume of each composition is compared with the cost of a typical ordinary cement concrete.

2. Aggregates and mixture design

Different light weight aggregates were prepared from “Shen Abad mine” in the North West of “Rafsanjan”. According to the geological studies, this region has rich and extensive mines of natural aggregates such as pumice (which is favorite lightweight aggregate for manufacturing low weight and high strengths concretes). A concrete material typically consists of three main parts (i.e. cement, aggregate and water). In order to obtain an optimum composition of light weight concrete, the size of aggregates is the main parameter for obtaining a low density mixture. Two kinds of natural lightweight aggregates (labeled by P_i and T_i symbols, respectively) were considered in the first part of this research for being used in the mixtures of lightweight concrete and for each aggregate type, the water absorption percentage and the density of aggregates were determined. Table 1 presents the results of the mentioned measurements for the two types of P_i and T_i aggregates.

Table 1
Water absorption percentage and the density of P_i and T_i aggregates

aggregate	Percentage of water absorption after 0.5hours	Percentage of water absorption after 24 hours	Density (gr/cm^3) @ oven-dry (air)	Density (gr/cm^3) @ saturated-surface-dry (SSD)
Type 1 (P_i)	12	12.5	1.28	1.35
Type 2 (T_i)	11	11.8	1.37	1.43

Fig. 1 shows the distribution of aggregate gradation used in this research for preparation of concrete mixture using the two aggregate types.

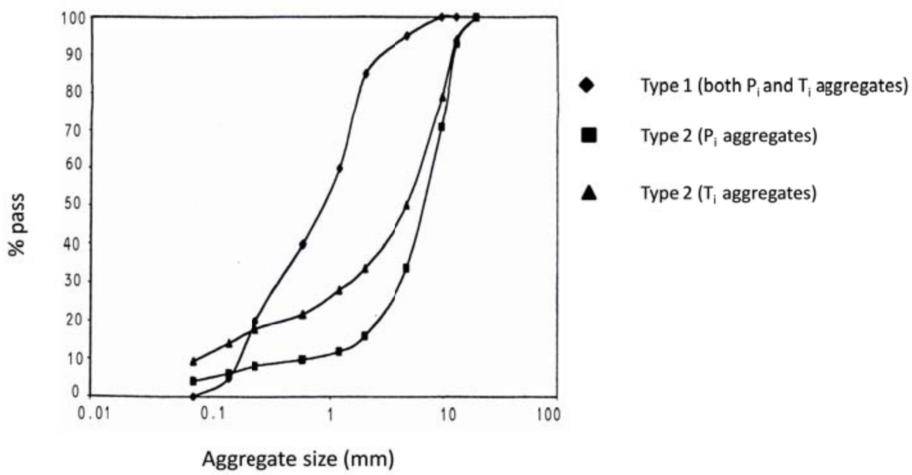

Fig. 1. Aggregate gradation of P_i and T_i samples.

Using the mentioned aggregates, several mixtures were designed according to ASTM C33. For each mixture the composition of concrete including the cement, water, aggregate and filler contents were determined based on the available formulations presented in ASTM C33. The mixture composition of each concrete has been presented in Table 2.

Table 2
Mixture composition of concretes with different aggregates

Sample No.	Condition of used aggregate	Aggregate gradation type	Cement content kg/m^3	Water content Lit/m^3	Aggregate content kg/m^3	Filler content Kg/m^3
P_1	SSD	2	300	150	300	-
P_2	SSD	2	450	200	320	-
P_3	SSD	2	450	180	-	Micro silica 70 super plasticizer 60
P_4	SSD	1	450	210	-	-
P_e	SSD	1	450	210	-	-
P_A	Dried at air	2	300	290	-	-
T_1	SSD	2	500	140	320	Micro silica 70 super plasticizer 60
T_2	SSD	2	500	230	320	-
T_3	Dried at air	2	450	260	-	-
T_e	SSD	1	450	200	-	-

The prepared mixtures were then inserted to molds of 100*100*100 mm^3 to obtain cubic test samples made from different compositions. At least 3 test samples were manufactured from each mixture and the test samples were maintained for 7, 14, 21 and 28 days. Then they were subjected to a compressive load (according to AASHTO (1995)) using a 10 kN test machine with the loading rate of 0.5 mm/min to obtain the compressive strength of the manufactured concretes. It should be noted that in addition to P_i and T_i samples, other lightweight aggregates available in the Kerman province such as Leca, Perlite, pumice and copper slag furnace were also used for manufacturing other lightweight concretes. In the next section, the experimental results are presented and discussed.

3. Results and Discussion

Table 3 summarizes the average of test results obtained for different light weight concretes. In Fig. 2 the compressive strength versus density of P_i and T_i samples have been compared. As seen from this figure, the mixtures made from T_i aggregates provide greater strengths in comparison with P_i samples. The cost of samples made from P_i and T_i samples with respect to ordinary cement concretes have been compared in Fig. 3. Based on this figure the mixtures made of T_3 and T_2 aggregates provide the highest compressive strength with the lowest cost.

Table 3
Results obtained for the density, compressive strength and cost of different lightweight aggregate concretes tested in this research

Sample name	Density (kg/m^3)	28days compressive strength (kg/cm^2)	Cost per metric volume/ cost per metric volume of ordinary concrete
P_1	1650	125	1.15
P_2	1670	200	1.2
P_3	1700	300	1.2
P_4	1630	163	1.2
P_e	1630	155	1.2
P_A	1640	350	2
T_1	1610	190	1.1
T2	1700	325	1.15
T3	1720	310	1.15
Te	1630	315	1.3
Leca	1370	230	2.2
perlite	980	160	1.3
Slag copper	1430	180	1.65
pumice	1480	90	1.4

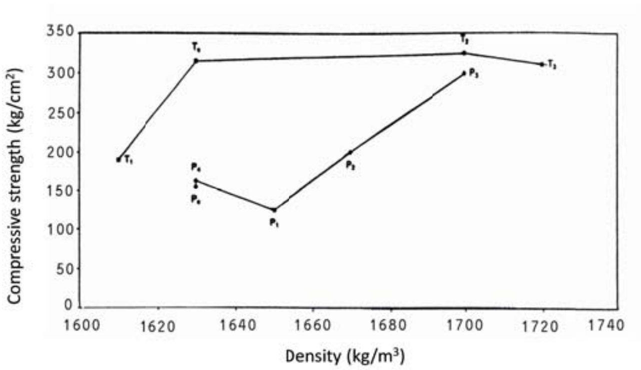

Fig. 2. Variations of compressive strength of different lightweight concretes made of P_i and T_i aggregates

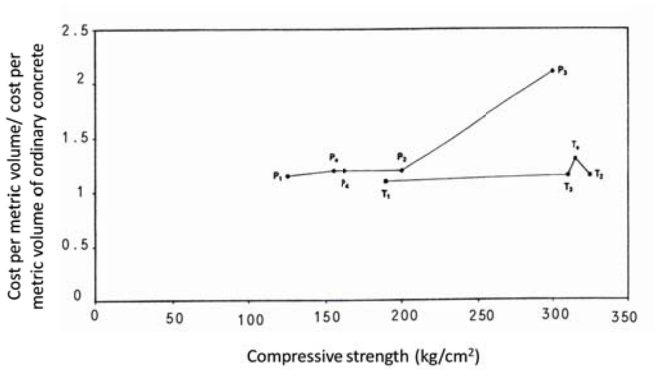

Fig. 3. Comparison of cost for different lightweight concretes made of P_i and T_i aggregates

As it is clear the percentage of aggregate might have noticeable influence on the strength properties of the concretes. Hence, in the following the effect of pumice aggregate is investigated for example on the strength properties of concrete. A few concrete mixtures (i.e. A,B,C,D,E and F) were prepared using pumice aggregates according to mix design of Table 4. Some of the characteristic specifications of the pumice light weight aggregates including the density and water absorption ability in terms of time were also measured experimentally before mixing. For example, Fig. 4 presents the water absorption percentages of pumice aggregate at different times. Values of density and compressive strength of pumice concrete after 7, 14, 21 and 28 days have been also presented in Table 5. It is seen from this Table that the samples C and D have the highest compressive strength value for all the concrete ages.

Table 4
Aggregate size and the percentage of pumice used for different concrete mix designs

Sample	% Pumice	Aggregate size (mm)			
		1-2	2-5	5-10	10-15
A	20	12	28	20	30
B	22	10	15	22	31
C	24	11	15	25	25
D	30	12	10	20	38
E	35	10	10	25	30
F	40	10	14	16	20

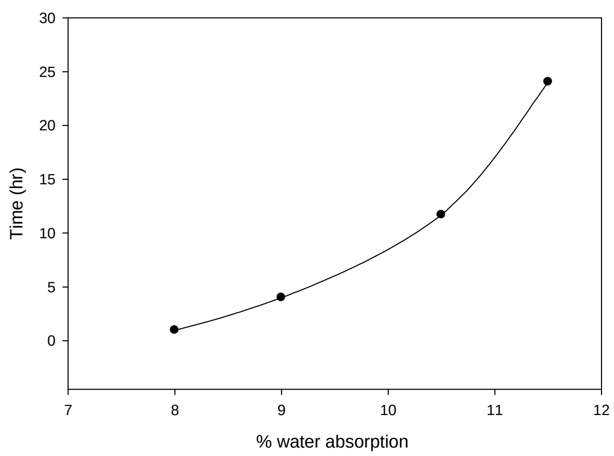

Fig. 4. Variations of water absorption of pumice aggregates with time

Table 5
Density and compressive strength of different pumice lightweight aggregate concretes

Sample	Density of pumice concrete		Compressive strength (kg/cm^2)			
	dry	SSD	7 days	14 days	21 days	28 days
A	1.47	1.65	120	230	250	290
B	1.45	1.50	110	240	265	300
C	1.38	1.40	105	245	270	310
D	1.35	1.38	105	250	265	315
E	1.30	1.35	104	245	260	307
F	1.29	1.32	102	240	260	305

Fig. 5 shows the variations of the 28 days compressive strength with pumice percentage. Based on this figure, by increasing the pumice percentage from 20 % to 24% in the composition of concrete, the compressive strength is increased but for pumice percentages greater than 30% the compressive strength of concrete is reduced. The maximum strength is achieved when the pumice content is between 24% and 30%.

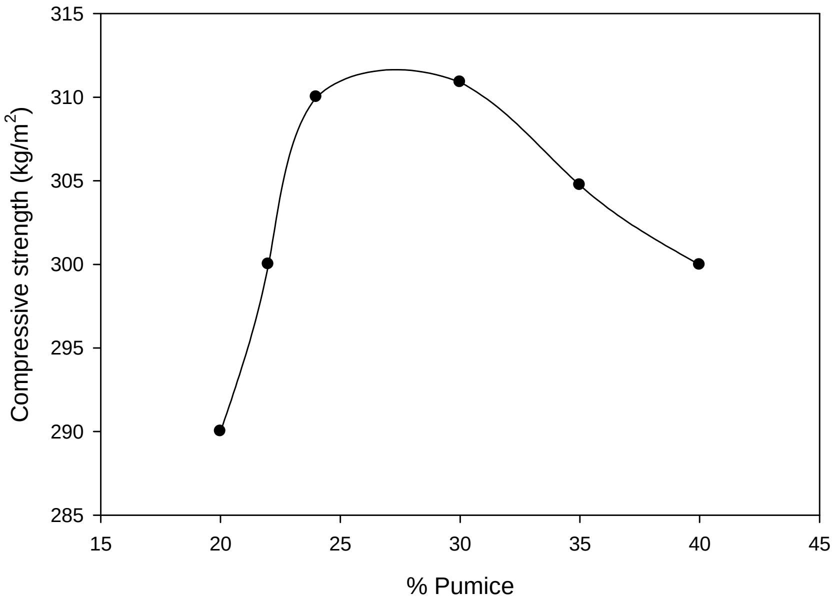

Fig. 5. Variations of 28days compressive strength with different percentages of pumice in the composition of concrete

4. Conclusions

- Different lightweight aggregate concretes with the aggregates that are frequently found in south east of Iran were designed and manufactured.
- The effects of aggregate type, composition and percentage of aggregates were studied on the density and compressive strength of light weight aggregate concretes.
- Samples T_2 and T_3 had the greatest strength and also lowest price. Hence, they can be considered as favorite concretes for being used in structural applications.
- The maximum strength for pumice concrete was obtained for mixtures containing 24% to 30% pumice aggregates.

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