Available online at www.sciencedirect.com
SCIENCE DIRECT
Cement & Concrete Composites 28 (2006) 481–485
Cement & Concrete Composites
www.elsevier.com/locate/cemconcomp

Engineering properties of lightweight aggregate concrete made from dredged silt

H.Y. Wang *, K.C. Tsai

Department of Civil Engineering and Disaster Mitigation Technology, National Kaohsiung University of Applied Sciences, Kaohsiung 80742, Taiwan, ROC

Received 25 January 2005; accepted 20 December 2005
Available online 30 January 2006

Abstract

Silt dredged from reservoirs can be hydrated and sintered into lightweight aggregate for producing lightweight aggregate concrete (LWAC). The densified mixture design algorithm (DMDA) was employed to manufacture LWAC using 150 kg/m^3 of water at different water-to-binder ratios (w/b = 0.28, 0.32 and 0.4) using lightweight aggregates of different particle densities (800, 1100 and 1500 kg/m^3). The engineering properties of the LWAC thus obtained were examined. Results show that the fresh concrete meets the design requirement of having slump of 250 ± 20 mm and slump flow of 600 ± 100 mm. With respect to hardened properties, the compressive strength, ultrasonic pulse velocity and thermal conductivity were found to decrease with increasing w/b ratio but increase with increasing aggregate density. Moreover, higher aggregate density also resulted in less shrinkage. The surface resistivity exceeding 20 kΩ-cm also matched the design objective. The experimental results prove that LWAC made from dredged silt can help enhance durability of concrete.

Keywords: Aggregate density; Silt; Lightweight aggregate; Densified mixture design algorithm

1. Introduction

Accumulation of silt is a common problem of reservoirs in Taiwan resulting in annual decrease in water storage capacity. While it is unlikely that new reservoirs will be constructed in the near future, the government has stepped up its effort in dredging the silt with the intention to maintain a stable supply of water and extending the service life of the reservoirs [1]. Nevertheless, improper disposal or treatment of the silt dredged may have detrimental effects on the environment and arouse public discontent. Taiwan, being densely populated and having limited natural resources, has developed technologies for the reuse of dredged silt from the reservoirs [2]. Since sands and stones needed for cement mixing are in short supply, reuse of dredged silt offers an economic and ecological alternative. Through hydration and high-temperature sintering, dredged silt is made into lightweight aggregate, which is then used to produce high-performance lightweight aggregate concrete (LWAC). Although there has been abundant and fruitful research carried out on the development and manufacturing techniques for LWAC [3], its application to engineering or public construction is less common than high-performance or traditional concrete [4]. In fact, LWAC is a very versatile material for construction. It offers a range of technical, economic and environment-enhancing and preserving advantages. Its properties have been widely studied [5] and its strength and durability have been proved to be good [6]. Compared with its normal-weight counterpart, lightweight aggregate has higher water absorption rate and lower relative density. In addition to being light, it has good strength, fire resistance and heat insulation. LWAC has been used in buildings and bridges to reduce the dead weight and the dimensions of structural

* Corresponding author. Fax: +886 7 396 1321.
E-mail address: wangho@cc.kuas.edu.tw (H.Y. Wang).

0958-9465/$ - see front matter © 2006 Elsevier Ltd. All rights reserved.
doi:10.1016/j.cemconcomp.2005.12.005

members. This research aims to study the properties of LWAC mixed using lightweight aggregates made from sintered silt dredged from reservoirs. Moreover, lightweight aggregates of different densities and various water-to-binder (w/b) ratios were used to examine their influence on engineering properties of LWAC.

2. Experimental study

2.1. Materials

The lightweight aggregate manufactured from dredged silt from reservoirs is a synthetic aggregate. Materials used in this study for making lightweight aggregate concrete include the ASTM C 150 compliant Type I ordinary Portland cement (OPC), fly ash from a local factory, blast-furnace slag from Chung Lien Factory, aggregates and natural sands according to ASTM C33, and Type 1000 superplasticizer which complies with the ASTM C 494 type G admixture. The chemical composition and physical properties of these materials are shown in Tables 1–3. The maximum size of LWA (1) used in the mixes is 20 mm and LWA (2) and LWA (3) are 13 mm.

2.2. Test variables

The densified mixture design algorithm (DMDA) was employed to mix the LWAC. In this study, the concrete was filled using 60% of lightweight aggregate and fly ash to replace 15% of sand required, slag to replace 5% of cement. With the basic materials and their chemical compositions known, the density of the lightweight aggregate and w/b ratio were varied to examine their effect on the properties and compressive strength of the fresh concrete. Lightweight aggregate of three different particle densities, namely 800, 1100 and 1500 kg/m^3, and three w/b ratios, namely 0.28, 0.32 and 0.40 were used. Table 4 shows the nine mix proportions for preparing LWAC.

Table 1
Chemical composition and physical properties of cement, fly ash and slag

Items	OPC	Fly ash (Type F)	Slag
Chemical composition (wt.%)			
SiO_2 (S)	22.01	51.23	34.86
Al_2O_3 (A)	5.57	24.31	13.52
Fe_2O_3 (F)	3.44	6.14	0.25
S+A+F	31.02	–	48.63
CaO (C)	62.80	6.28	41.77
MgO (M)	2.59	1.61	7.18
SO_3 (S)	2.08	0.61	1.74
f-CaO	1.05	–	–
TiO_2 (T)	0.52	1.42	–
Na_2O (Na)	0.40	0.21	–
K_2O (K)	0.78	1.16	–
V_2O_5 (V)	0.05	–	–
Loss on ignition (LOI)	0.51	4.85	0.31
Physical properties			
Fineness (m^2/kg)	297	311	435
Specific gravity (g/cm^3)	3.15	2.19	2.87
Initial setting time (h:min)	1:25	–	–
Final setting time (h:min)	2:31	–	–
28-day mortar cube strength (MPa)	56	–	–
Retention on 325 sieve (%)	–	–	8.0

Table 2
Physical properties of aggregates

Physical properties	Coarse aggregate (>4 mm)			Fine aggregate (<4 mm)
	LWA (1)	LWA (2)	LWA (3)	Natural sand
Particle density (kg/m^3)	800	1100	1500	2630
Absorption capacity (24 h) (%)	9.6	8.0	4.2	0.9
Max. size D_{max} (mm)	20	13	13	2.4
Fineness modulus (FM)	6.95	6.48	6.40	2.88
Unit weight (kg/m^3)	498	658	836	1650
Compressive strength (MPa)	2.66	3.33	6.74	–

Table 3
Basic properties of superplasticizer

Properties	Type 1000 superplasticizer
Solid ingredient (%)	43.0
Chloride ion content (ppm)	50.1
Insoluble residue (%)	0.15
Specific gravity (g/cm^3)	1.18
pH value	6.93

2.3. Test measurements

The concrete was mixed according to the specifications of ACI 211.4R. The DMDA was employed to achieve the maximum unit weight while minimizing internal porosity [7]. The slump and slump flow of the fresh concrete were determined in accordance with ASTM C143. The test specimens for compressive strength were 100×200 mm cylinders as per ASTM C31 and C39, while the pulse velocity was measured according to ASTM C597. Electrical resistance coefficient of LWAC was measured by the concrete resistivity meter (CNS Electronics Ltd.). Specimens of $40 \times 200 \times 200$ mm were made according to DIN 51046 for measuring the coefficient of thermal conductivity on the surface at 10 °C and 40 °C using a quick thermal conductivity meter (QTM-D2). The drying shrinkage specimens of $101.6 \times 101.6 \times 279.4$ mm were demolded 24 h after casting, and cured under water at a temperature of 23 ± 2 °C for 28 days. The above measurements were taken to examine the effect of lightweight aggregate density and w/b ratio on the fresh and hardened properties of the LWAC, which would also shed light on the workability, homogeneity and durability of LWAC.

Table 4
Mix proportions of lightweight aggregate concrete

Particle density (r) (kg/m^3)	Batch	w/b	w/c	Materials (kg/m^3)								
				Sand	L. agg	Cement	Fly ash	Slag	Water	SP	W_{total}	Unit weight
800	U0828150	0.28	0.39	751	283	383	133	20	123	27	150	1720
	U0832150	0.32	0.48	774	292	315	137	17	134	16	150	1685
	U0840150	0.4	0.68	807	304	221	143	12	144	6	150	1637
1100	U1128150	0.28	0.39	751	426	383	133	20	125	25	150	1863
	U1132150	0.32	0.48	774	440	315	137	17	138	12	150	1833
	U1140150	0.4	0.68	807	459	221	143	12	144	6	150	1792
1500	U1528150	0.28	0.39	751	570	383	133	20	126	24	150	2007
	U1532150	0.32	0.48	774	588	315	137	17	138	12	150	1981
	U1540150	0.4	0.68	807	613	221	143	12	144	6	150	1946
1100 (ACI)	U1128223	0.28	0.28	417	409	796	0	0	200	23	223	1845
	U1132223	0.32	0.32	504	409	697	0	0	223	0	223	1833
	U1140223	0.4	0.4	625	409	558	0	0	223	0	223	1815

b: Binder including cement, fly ash and slag; SP: Type 1000 superplasticizer ASTM C494 HRWRA, naphthalene-based; SP (%): weight of superplasticizer to binder content ratio; W: clean water, including water in the superplasticizer.

3. Test results and discussion

3.1. Properties of fresh concrete

Table 5 shows the properties of fresh concrete mixed with 150 kg/m^3 of total water using LWAC of various densities at different w/b ratios. The initial slump of the fresh concrete was found to be 250 ± 20 mm and the slump flow was 600 ± 100 mm. Even after 60 min, the workability of the fresh concrete was maintained, showing neither water bleeding nor segregation of aggregate.

3.2. Compressive strength

Fig. 1 shows the relationship between compressive strength and aggregate density at different w/b ratios. As expected, there is enhancement in compressive strength with higher aggregate density and lower w/b ratio. However, the differences in compressive strength become less significant with longer curing as evidenced by the smaller increase after 56 days of curing. This reduction in strength development is constrained by the strength of the lightweight aggregate.

3.3. Ultrasonic pulse velocity

Fig. 2 shows the variation of ultrasonic pulse velocity and aggregate density and therefore compressive strength at different w/b ratios. As seen in the figure, the pulse velocity of concrete of different mix proportions all reached 3900 m/s after 90 days of curing.

3.4. Electrical resistivity

Fig. 3 shows the changes in electrical resistivity of LWAC with different w/b ratios. As expected, the lower the w/b ratio, the higher the electrical resistance. Low w/b ratio resulting in greater durability of concrete is also

Table 5
Properties of fresh LWAC

Particle density (r) (kg/m^3)	Batch	Initial			At 60 mins		
		Slump (mm)	Slump flow (mm)	Flow time (s)	Slump (mm)	Slump flow (mm)	Flow time (s)
800	U0828150	270	615	190	265	610	195
	U0832150	260	610	150	255	595	180
	U0840150	260	560	115	250	540	145
1100	U1128150	275	670	115	270	660	120
	U1132150	265	615	160	260	600	180
	U1140150	260	650	40	250	630	60
1500	U1528150	270	685	150	260	630	170
	U1532150	255	560	135	240	520	180
	U1540150	245	650	70	235	550	100
1100 (ACI)	U1128223	130	–	–	50	–	–
	U1132223	105	–	–	55	–	–
	U1140223	150	–	–	110	–	–

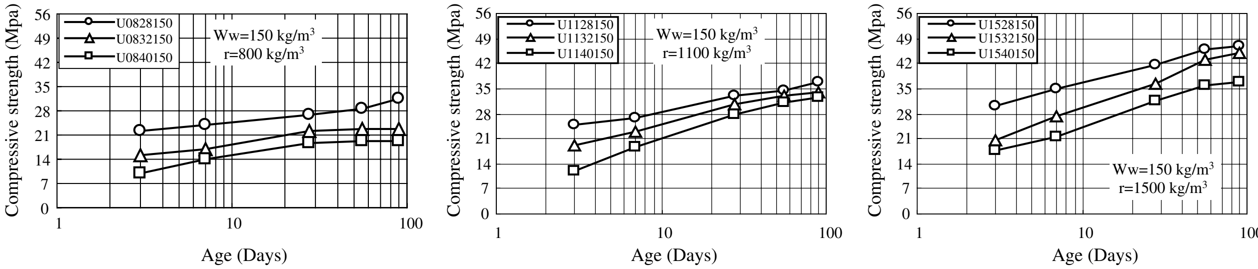

Fig. 1. Relationship between compressive strength and aggregate density at different w/b ratios.

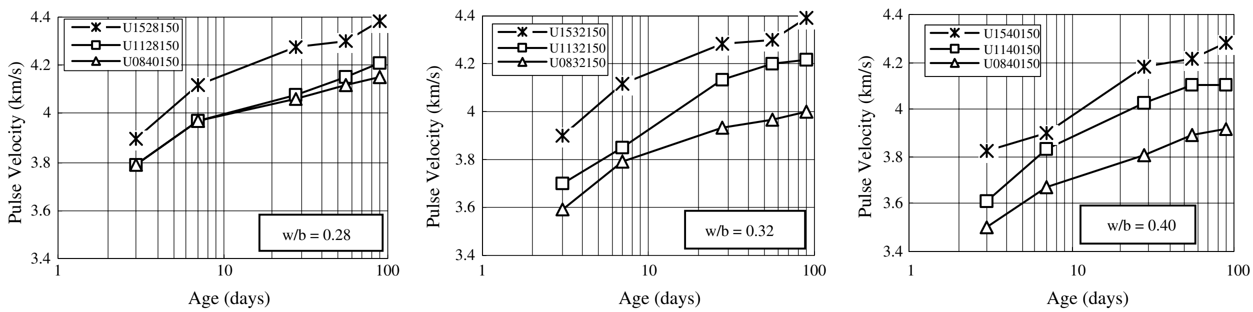

Fig. 2. Relationship between ultrasonic pulse velocity and aggregate density at different w/b ratios.

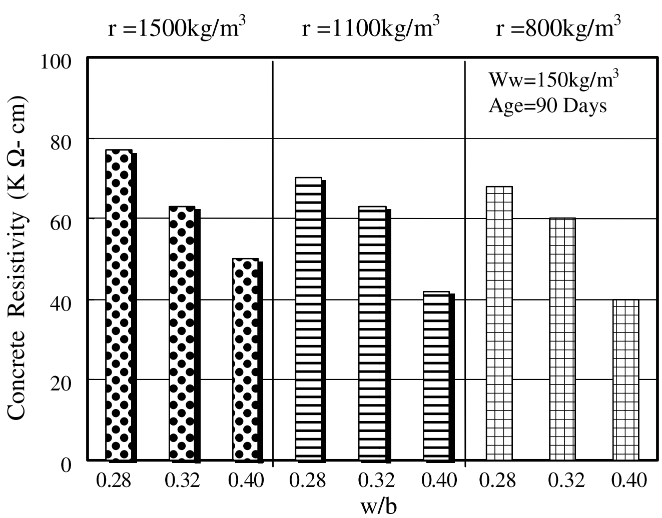

Fig. 3. Relationship between electrical resistivity with different aggregate densities and w/b ratios after 90 days of curing.

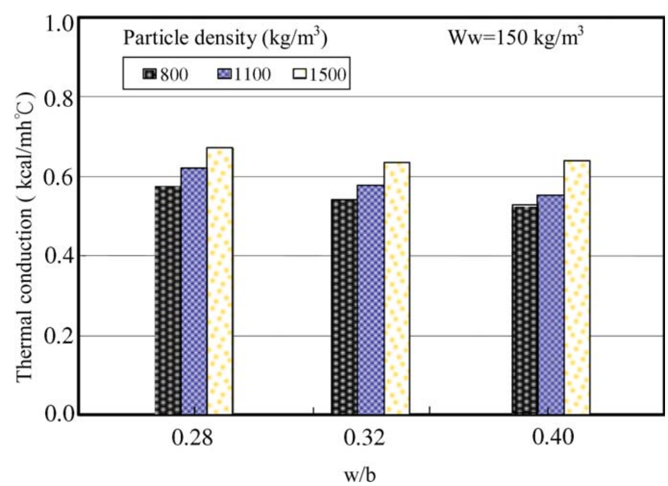

Fig. 4. Relationship between thermal conductivity coefficient with different aggregate densities and w/b ratios.

evidenced by the better compressive strength and higher ultrasonic pulse velocity. For the same w/b ratio, aggregate of greater density will increase electrical resistivity. The electrical resistivity of the LWAC reached above 40 kΩ-cm after 90-day curing.

3.5. Thermal conductivity coefficient

Fig. 4 shows the thermal conductivity coefficient under different aggregate densities and w/b ratios. As expected, thermal conductivity of the concrete is related to the apparent density: the lower the aggregate density, the smaller the thermal conductivity coefficient will be. In this study, the effect of different w/b ratios on thermal conductivity was found to be not significant because the amounts of aggregate used are almost the same. The coefficient of LWAC, being 0.5–0.7 kcal/m h °C, is much smaller than that of normal-weight concrete (1.0–1.5 kcal/m h °C), implying better heat insulation of LWAC.

3.6. Shrinkage

Table 6 shows the expansion at 28 days and the shrinkage at 90 days. The results show on expansion varying from

Table 6
Expansion and shrinkage of LWAC (w/b = 0.32)

Particle density (*r*)	Batch	Expansion at 28 days	Shrinkage at 90 days
800	U0832140	110	450
	U0832150	130	462
	U0832160	150	510
1100	U1132140	100	390
	U1132150	120	500
	U1132160	144	510
1500	U1532140	110	410
	U1532150	110	418
	U1532160	110	430

100 to 150×10^{-6} whereas at 90 days the shrinkage varied from 390 to 510×10^{-6}.

4. Conclusions

From the study reported here, the following conclusions can be drawn.

1. The DMDA has proved to be capable of producing LWAC mixes with a slump of 230 mm and slump flow above 500 mm while avoiding bleeding and segregation.
2. With a particle density of 800 kg/m^3, the 28 day compressive strength reached 20–30 MPa; while it reached 30–40 MPa at particle density of 1100 and 1500 kg/m^3.
3. The LWAC reported here developed a pulse velocity above 3900 m/s after curing for 90 days.
4. LWAC mixes using the DMDA has better electrical resistivity, above 40 kΩ-cm after 90-day curing.
5. The thermal conductivity coefficient of LWAC ranged between 0.5–0.7 kcal/m h °C, which is far smaller than that of normal-weight concrete.
6. Expansion after 28 day water curing reached a maximum of around 150×10^{-6}, while the maximum shrinkage at 90 days was 510×10^{-6}.

References

[1] Lin JJ. View on dredging the silt in Taiwan area reservoirs. In: The workshop on dredging reservoir silt, Taichung, 2002.
[2] Yang FR. Water resource exploitation and utilization in southern Taiwan. Civ Hydraulic Eng 2003;30(2):26–33.
[3] Yen T. Investigations of chemical properties for dredged mud of reservoirs in Taiwan and the manufacturing techniques of lightweight aggregate. In: Proceedings of conference on manufacturing and applications of lightweight aggregate concrete from the silts of reservoirs, Taipei, December 2003, p. 3–20.
[4] Wang HY. Study on chemical properties and lightweight aggregate production using silt of Taiwan southern reservoirs, Final report of the research plan of lightweight aggregate production by reservoir silt, utilization and promotion of lightweight aggregate concrete, Energy Conservation Lightweight Aggregate Association, 2003.
[5] Tsai CH. Study on the properties of sintered lightweight aggregate concrete, B.A. Thesis, National University of Science and Technology, Department of Construction Engineering, Taipei, Taiwan, 2001.
[6] Haque MN, Al-Khaiat H, Kayali O. Strength and durability of lightweight concrete. Cem Concr Compos 2004;26:307–14.
[7] Chang PK. An approach to optimizing mix design for properties of high-performance concrete. Cem Concr Res 2004;34:623–9.