International Journal of GEOMATE, Nov., 2020, Vol.19, Issue 75, pp.1-7
ISSN: 2186-2982 (P), 2186-2990 (O), Japan, DOI: https://doi.org/10.21660/2020.75.45596
Geotechnique, Construction Materials and Environment

INFLUENCE OF COARSE AGGREGATES AND MORTAR MATRIX ON PROPERTIES OF LIGHTWEIGHT AGGREGATE CONCRETES

Hoang Vinh Long

Faculty of Building Materials, National University of Civil Engineering, Vietnam

Received: 19 May 2020, Revised: 03 June 2020, Accepted: 13 June 2020

ABSTRACT: Lightweight Aggregate Concrete (LWAC) with many advantages such as low density, good insulating capacity, and high fire resistance has been widely used around the world. LWAC may be considered as a two-component composite material consisting of a coarse aggregate and mortar matrix. The characteristics of these two components affect the properties of LWAC especially homogeneity. Therefore, this paper presents research results of the influence of lightweight coarse aggregates and mortar matrix on properties of this type of concrete. In the study, the raw materials were keramzit, polystyrene foam, type I cement, class F fly ash, and R4 plasticizer. A Suttard viscometer was mainly used to evaluate the workability named the flow of mortar. The experimental results showed that slump and segregation of concrete mixtures were remarkably increased when the flow of mortar was ≥ 21 cm; and the compressive strength of concrete was only about 40% and 20% the mortar strength when keramzit and polystyrene foam was used as coarse aggregates in the concretes respectively.

Keywords: Lightweight aggregate concrete, Viscosity, Mortar flow, Segregation

1. INTRODUCTION

According to ACI 213R- 14 [1], the density of LWAC is less than 1920 kg/m^3, then smaller than 25% compared with normal-weight concrete. That reduces dead load and costs of supporting structures, enhance the architectural expression or construction of a structure, and reduces transportation costs. Simultaneously, LWAC has a good capacity for thermal insulation and fire resistance.

LWAC may be considered as a two-phase material containing coarse aggregate inclusions within a continuous mortar matrix that includes cement, water, entrained air, and fine aggregate. Many types of Lightweight Aggregates (LWA) have been used for LWAC, however, they could be classified as two types including natural LWA from volcanic materials, and artificial LWA commonly from some industrial wastes or expanded shale, clay, and slate, etc. Relative density of LWA is in a wide range of 15-1200 kg/m³, that is much less than the density of mortar of 2000-2400 kg/m³. This may cause the phenomenon of segregation significantly affecting other properties of LWAC.

During the mixing and placing process, lower-density coarse LWA tends to move upward and heavier mortar moves in the opposite direction. The relative movements of the two components could be expressed in the Stokes equation as following:

$$v = 2r^2\left(\rho_{mortar} - \rho_{LWA}\right)\frac{g}{9\eta} \tag{1}$$

In which, v is the velocity of coarse LWA movement (m/s); r is the radius of LWA particle (m); ρ_{mortar} is the density of mortar (kg/m³); ρ_{LWA} is the relative density of LWA particle (kg/m³); g is the gravitational acceleration (m/s²); η- the dynamic viscosity of mortar (Ns/m²).

Currently, LWAC mixture designs are often applied for concrete using aggregates of keramzit and agloporit [2-4]. That makes it difficult to design for LWAC's compositions using other types of lightweight aggregates [5]. Therefore, this paper presents the results of the study of the influence of the LWA and mortar matrix on the properties of lightweight concrete. The outcome of the research could contribute to determining compositions of LWAC using different types of LWA.

2. MATERIALS AND METHODS

2.1 Materials

2.1.1 Binder (B)

Binder mixtures with different ratios of cement and fly ash were used in this study. The Fly Ash (FA) could be classified as F class according to ASTM C 618-19. The cement has the physical properties meet requirements of Type I cement of ASTM C150-19. Physical properties of the fly ash and the cement are given in Table 1 and Table 2 respectively. The chemical compositions of the cement and fly ash are presented in Table 3.

Table 1 Physical properties of the fly ash

Properties	Unit	Result
Specific gravity	g/cm^3	2.26
Strength activity index at age of 28 days	%	87
Average particle size	µm	7.87

Table 2 Physical properties of the Type I cement

Properties	Unit	Result
Specific gravity	g/cm^3	3.1
Fineness		
- Retained 0.09 mm	%	3.5
- Average particle size	µm	11.1
Normal consistency	%	29
Soundness	mm	0.2
Setting time		
- initial setting time	minutes	115
- final setting time	minutes	225
Compressive strength		
- 3 days	MPa	28.7
- 28 days	MPa	47.9

Table 3 Chemical compositions of the cement and fly ash (%)

	Cement	Fly ash
SiO_2	20.3	53.47
Fe_2O_3	5.05	28.47
Al_2O_3	3.51	5.17
CaO	62.81	1.31
MgO	3.02	1.59
Na_2O	-	-
K_2O	-	4.72
SO_3	2	-
TiO_2	-	-
LOI	1.83	5.07

2.1.2 Aggregates

Coarse LWAs including two types of keramzit with the maximum diameter at 20 mm (K20) and 7 mm (K7) and polystyrene foam with a maximum diameter at 7 mm (P7) were used. The physical properties of the coarse aggregates are shown in Table 4. A fine aggregate from a river with fineness modulus at 2.5 is satisfied with the specification of ASTM C33-18.

Table 4 Physical properties of coarse aggregates

Properties	Keramzit 7 (K7)	Keramzit 20 (K20)	Polystyrene (P7)
Maximum particle size (mm)	7	20	7
Bulk density (kg/m^3)	480	390	9.5
Relative denstiy (in dry) (kg/m^3)	950	760	25
Relative denstiy (in saturated surface dry) (kg/m^3)	1095	929	-

2.1.3. Plasticizer R4

R4 is a water-reducing and set-retarding admixture to produce concrete with high workability in conditions of a hot climate and with low ratio of water to binder to increase compressive strength.

2.2 Methods

Besides standard test methods, some other methods of experiment and material preparation are used described as below.

2.2.1 Determine binder paste viscosity

Viscosity experiments of binder paste were carried out using a viscometer SV-10. After mixed, a paste was taken about 35-45 ml to test.

Fig.1 Viscometer SV-10

2.2.2 Determine the flow of binder paste and mortar

A Suttard viscometer was used to study the flow characteristic of binder paste and mortar [6]. The Suttard viscometer includes a cylindrical tube with an internal diameter×height= 50×100 mm, made from stainless steel and mica or glass-bottom plate. Flow value is the average diameter in two perpendicular directions of paste or mortar samples after dispersion.

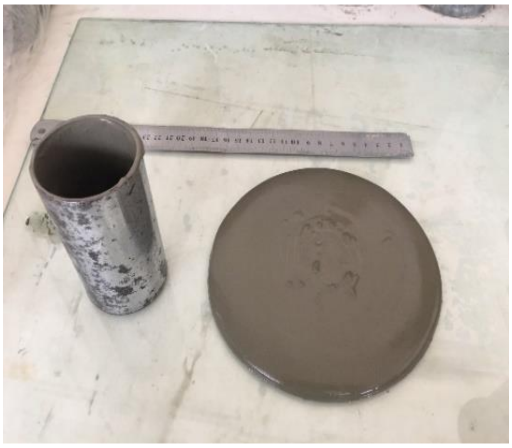


Fig.2 Suttard viscometer

2.2.3 Determine segregation of concrete mixture

Some methods could be used to determine segregation of concrete mixture such as density difference [7], ultrasonic velocity [8], electrical resistivity [9] In this study, the density difference method was used. Concrete mixture was compacted in a 5-liter container on a vibration table for 15 sec. Then the density of the lower half part and the upper half part concrete mixture in the container were determined. The segregation of concrete mixture is the ratio of the density difference of the two parts to the average density of concrete mixture [7].

2.2.4 Prewetting method for keramzit

Normally, because of the high water absorption of LWAs, the amount of water absorbed into an aggregate is typically calculated to add to the concrete mixture. On the other hand, LWA needs to be prewetted before mixing [10]. In this study, keramzit was soaked in 24 hours then drained within 1h before mixing concrete.

3. RESULTS AND DISCUSSION

3.1 Viscosity of Binder Paste

The viscosity of binder paste may influence not only rheology properties and but also segregation. Therefore, the research on the change of the paste viscosity overtime is necessary to control the workability of a concrete mixture. Contents of FA in the binder (B) consisting of cement and FA were 0%, 15%, and 30%. The pastes at the ratio of water to binder (W/B) of 0.35 and 0.4 were tested. The ratio of R4 to binder by weight was fixed at 0.35%.

As shown in Fig.3, the viscosity of all pastes was gradually increased over time. A ratio of W/B= 0.4, the viscosity of pastes was much less than that at the rate of 0.35 respectively. The increase of FA content not only caused remarkably decreasing of paste viscosity but also stably maintaining the viscosity.

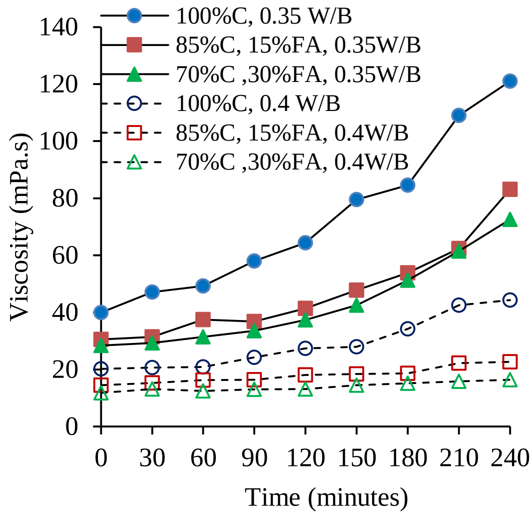


Fig.3 Change of the paste viscosity over time

3.2 Properties of Mortar

The compositions of mortar were used with the ratio of W/B at 0.35 and 0.4. The content of FA in the binder was 0%, 15%, and 30% by weight. The ratio of the fine aggregate to mortar by volume ($V_{F.Agg}/V_M$) was 0.4. The ratio of R4 to binder was fixed at 1%. To evaluate the effect of fine aggregate on the flow of mortar, flow experiments of pastes with the same compositions of mortars deducted fine aggregate was conducted. Some properties of pastes and mortars are shown in Table 5.

3.2.1 Flow of mortar

As presented in Table 5 and Fig.4, the higher content of FA the higher flow of mortar, namely, at W/B=0.35 flow of mortar increased 5.3% with FA/B=15% and 7.9% with FA/B=30% compared with mortar without FA; respectively 2.4% and 4.8% at a ratio of W/B=0.4.

Table 5 Properties of pastes and mortars

No	W/B	R4/B	FA/B	$V_{F.Agg}/V_M$	Flow of pastes (cm)	Flow of mortars (cm)	The density of mortar mixture (kg/m^3)	Compressive strength of mortar at 28 days (MPa)
M1	0.35	1.0%	0%	0	27.5			
				0.4		19	2249	58.2
M2			15%	0	28			
				0.4		20	2171	50.6
M3			30%	0	29			
				0.4		20.5	2150	49.2
M4	0.4	1.0%	0%	0	30			
				0.4		21	2187	45.8
M5			15%	0	30.75			
				0.4		21.5	2107	41.3
M6			30%	0	33.25			
				0.4		22	2076	35.9

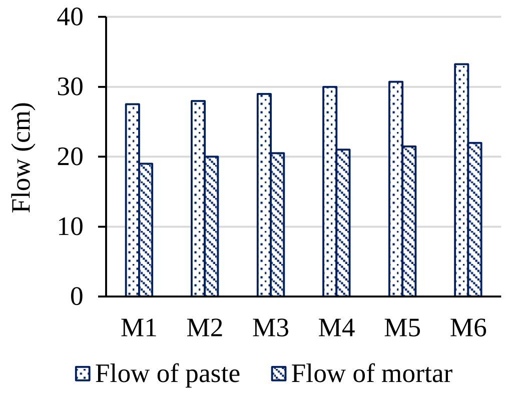


Fig.4 Comparing flow of mortar with the flow of paste

The flow value of mortar fell about 25-30% compared to the corresponding flow of paste. That indicated effect of the fine aggregate in increasing shear stress and decreasing the workability of mortar.

3.2.2 Compressive strength of mortar

As shown in Fig.5, the strength of mortar was 38-50 MPa. The compressive strength of mortar was significantly decreased when the ratio of W/B and FA replaced content was increased.

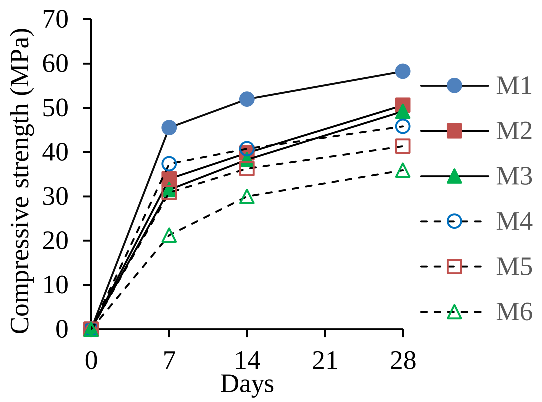


Fig.5 Development of compressive strength of mortars

Table 6 Some properties of LWACs using keramzit and polystyrene

No	$V_{C.Agg}/V_C$	N/B	FA/B	Slump (cm)	Segregation (%)	Density of fresh concrete (kg/m^3)	f'$_c$ at 28 days (MPa)	The density of dried concrete (kg/m^3)
K20.50.1	50%	0.35	0%	0	1.7%	1598	15.6	1468
K20.50.2			15%	0	1.8%	1547	14.8	1427
K20.50.3			30%	0	2.8%	1596	14.5	1402
K20.50.4		0.4	0%	1	6.7%	1578	17.7	1465
K20.50.5			15%	2	5.5%	1531	14.6	1461
K20.50.6			30%	2.5	6.7%	1547	14.5	1426
K20.40.1	40%	0.35	0%	2	1.9%	1686	23.5	1505
K20.40.2			15%	2.5	1.2%	1661	18.5	1507
K20.40.3			30%	2.5	1.9%	1678	15.3	1511
K20.40.4		0.4	0%	7	6.1%	1639	18	1481
K20.40.5			15%	7	8.7%	1640	15.5	1488
K20.40.6			30%	8	8.9%	1608	14.4	1480
K7.40.1	40%	0.35	0%	-	-	-	-	-
K7.40.2			15%	3.5	0.3%	1681	20.1	1530
K7.40.3			30%	5.5	1.4%	1682	18.3	1509
K7.40.4		0.4	0%	7	2.2%	1658	21.8	1471
K7.40.5			15%	16	4.0%	1710	19.7	1489
K7.40.6			30%	17	5.6%	1667	17.6	1481
P7.50.1	50%	0.35	0%	1.5	3.7%	1316	10.2	1246
P7.50.2			15%	1.5	11.2%	1275	8.8	1232
P7.50.3			30%	1.5	10.3%	1292	8	1185
P7.50.4		0.4	0%	15.5	14.2%	1249	9.8	1162
P7.50.5			15%	16.5	33.6%	1299	8.5	1126
P7.50.6			30%	13	26.1%	1156	7.9	1096

3.3 Influence of Aggregates and Mortar on Properties of LWACs

The composition of concrete was based on that of mortars as motioned in section 3.2 and combined with K20, K7, and P7 at the ratio between coarse aggregate to concrete mixtures $V_{C.Agg.}/V_C$=40% and 50% by volume. Some properties of LWACs is presented in Table 6.

3.3.1 Influence of aggregates and mortar on the slump of fresh LWACs

As shown in Fig.6, the larger flow of mortar the higher slump of a concrete mixture. Especially, the slump remarkably increased when the flow was ≥ 21 cm. It means that shear stress of concrete mixture is significantly changed when the workability of mortar did not vary much.

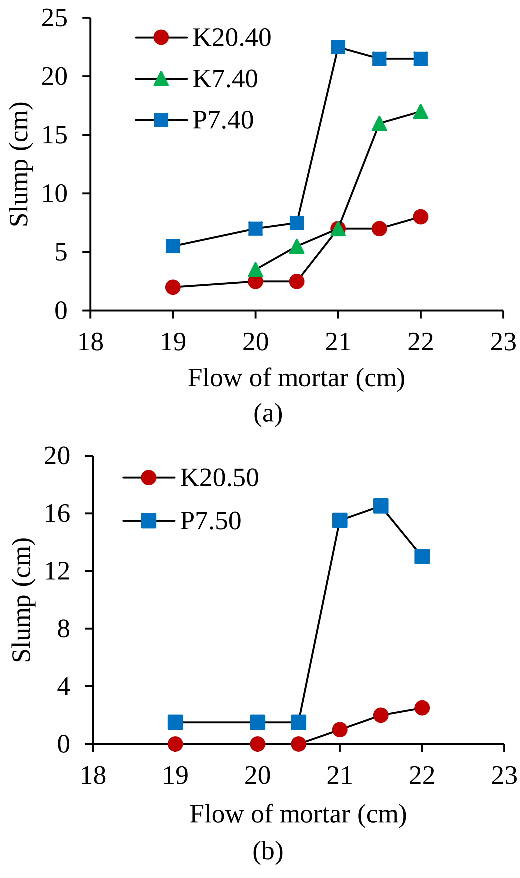


Fig.6 Influence of aggregates and mortar on the slump of fresh LWACs:
(a) $V_{C.Agg.}/V_C$ =40%, (b) $V_{C.Agg.}/V_C$=50%

The slump of K7.40 mixtures with smaller diameter of coarse aggregate was higher than that of K20.40 mixtures respectively. The slump of concretes with polystyrene was higher than that of concrete using keramzit aggregates. It is explained that the polystyrene particle has uniformly round shape, smooth surface texture, and low water absorption.

The workability of concrete mixtures with 40% by volume of coarse aggregates was mostly higher than 5 cm. Except for the case of K.20 concrete, the slump was about 2.5 cm when the flow of mortar was in the range of 19- 20.5 cm. When the content of polystyrene was raised to 50% by volume, the slump of concrete was considerably decreased by about 5 cm comparing with that of 40% respectively. Meantime, concrete mixtures using keramzit were nearly unworkable with less than 2.5 cm of the slump.

3.3.2 Influence of aggregates and mortar on segregation of fresh LWACs

As shown in Fig.7, it is clear that the smaller relative density of coarse aggregate particle the higher segregation. Most of the concrete mixtures with the density of polystyrene at 25 kg/m^3 had segregation higher than 10%. On the contrary, the segregation of all mixtures with keramzit aggregates was lower than 10%. K20 aggregates with 760 kg/m^3 of relative density partly caused 1.5 times higher of segregation of K7 aggregates with 950 kg/m^3 of relative density.

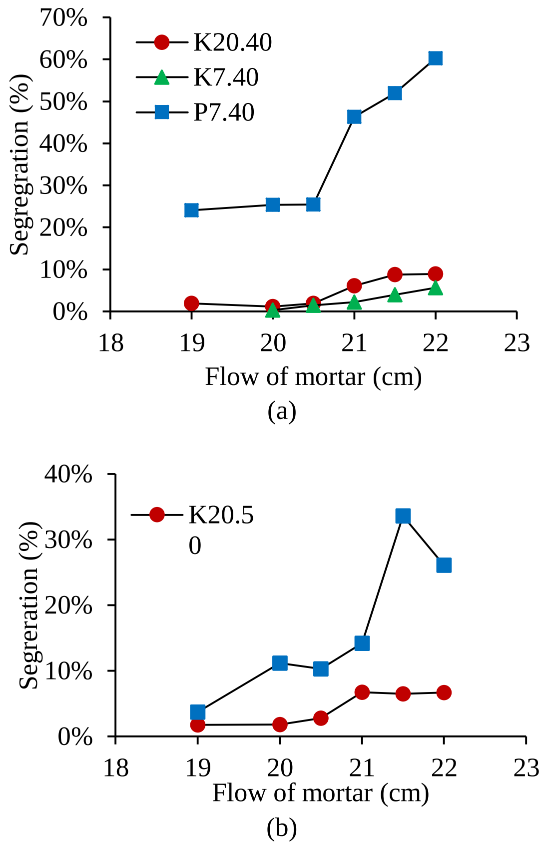


Fig.7 Influence of aggregates and mortar on segregation of fresh LWACs
(a) $V_{C.Agg.}/V_C$ =40%, (b) $V_{C.Agg.}/V_C$=50%

As the same influence on the slump, segregation of concrete was significantly increased about 2.5 times respectively when the flow of mortar was higher than 21 cm. At the same time, the volume of mortar also affected segregation especially concrete mixtures with polystyrene. Segregation of P7 concrete with 60% content of mortar was 2 times higher than that of 50% respectively. The increasing distance between coarse aggregate may cause decreasing of shear stress that prevents the movement of aggregate particles.

According to the standard GOST P 51263-2012, the segregation of LWAC should be less than 25%. All of keramzit concrete meet this requirement. However, segregation of P7 concrete mixtures with a higher 10 cm of slump mostly higher than 25%. This is quite appropriate as recommended by ACI 213R-14 to control the slump <10 cm to ensure homogeneous of a mixture of structural lightweight concrete.

3.3.3 Influence of aggregates and mortar on the density of LWACs

It is clearly shown in Fig.8 that relative density and content of coarse aggregate remarkably effect on the density of fresh concrete and dry hardened concrete. The density of fresh concrete reduced to 73% and 78% of the density of mortar mixtures when keramzit occupied 50% and 40% by volume. In case of polystyrene, the deacrease were 59% and 67% respectively.

The density of dried LWAC specimens using two types of keramzit was approximately the same at 1500 kg/m^3 when the content of aggregate at 40% by volume. The reason is moisture absorbed in both of two type aggregates was completely evaporated when the concrete specimens were dried. At 50% of the content of keramzit, the density of concrete was about 1440 kg/m^3. Meanwhile, the density of polystyrene concrete was averagely 1310 kg/m^3 and 1170 kg/m^3 with 40% and 50% of polystyrene content.

Decreasing trends of dry density of concrete with increasing both of fly ash replacement and the ratio W/B were also observed. It could be explained due to lower gravity density of fly ash comparing with cement; and a higher amount of evaporated moisture from mixing water.

3.3.4 Influence of aggregates and mortar on compressive strength of LWACs

Compressive strength at the age of 28 days of K7.40 specimens was about 19.5 MPa; and that was 17.5 MPa and 15 MPa of K20.40 and K.20.50. Additionally, the strength of concrete using polystyrene was 11 MPa and 9 MPa corresponding to the content of the foam of 40% and 50%. Hence, only the concrete with 40% content of keramzit could be classified as a structural lightweight concrete according to ACI 213R-14.

It can be observed in Fig.9 that, the compressive strength of the LWACs suddenly decreased comparing with that of mortar. For example, the strength of concrete using polystyrene foam was only 24% with V_{P7}/V_C=40% and 19% with V_{P7}/V_C =50%. Meanwhile, keramzit concrete's strength was 37% with V_{K20}/V_C=40%, 33% with V_{K20}/V_C=50% and 44% với V_{K7}/V_C=40%. It is clear that the strength and content of the aggregates much affect the compressive strength of concretes. Additionally, the higher fly ash content the lower the compressive strength of mortar, which caused the lower the strength of concretes.

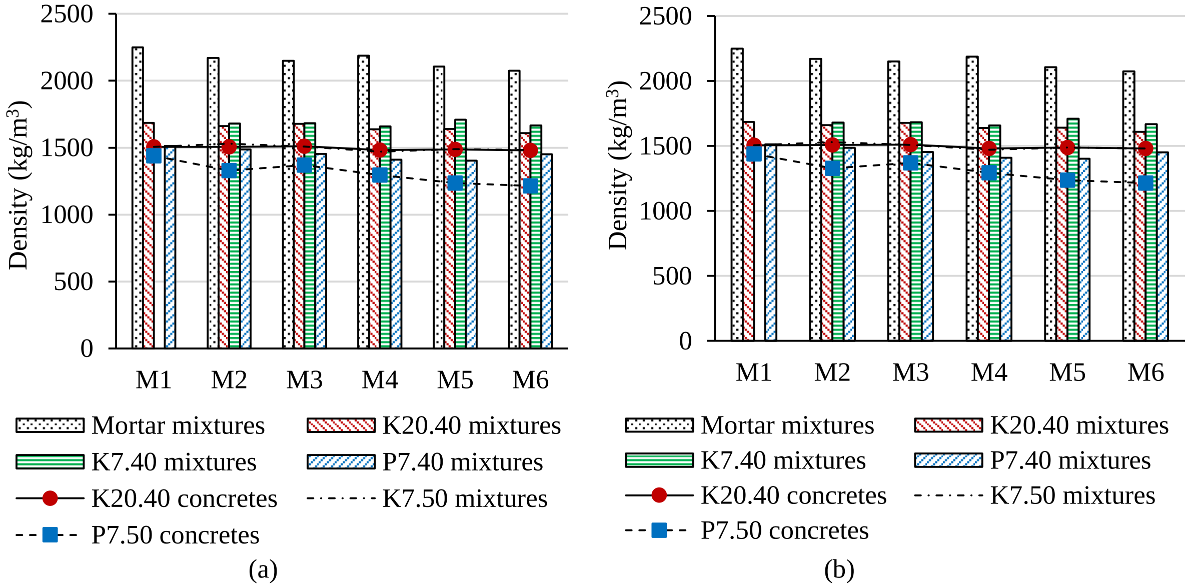
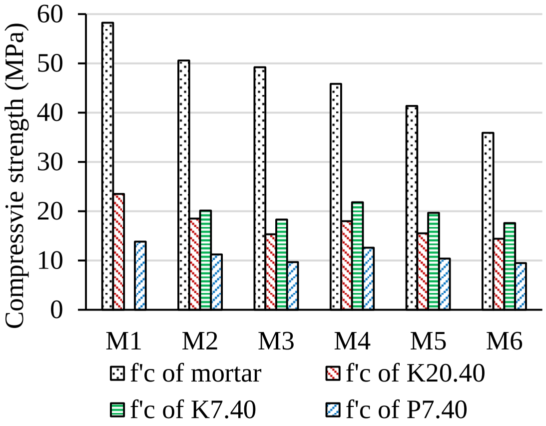
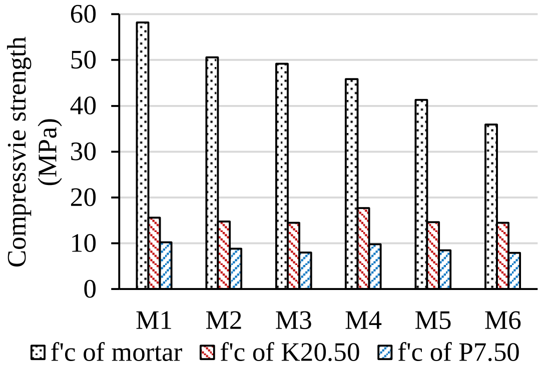


Fig.8 Influence of aggregates and mortar on density of LWACs (a) $V_{C.Agg.}/V_C$ =40%, (b) $V_{C.Agg.}/V_C$=50%



(a)



(b)

Fig.9 Influence of aggregates and mortar on compressive strength of LWACs
(a) $V_{C.Agg.}/V_C$ =40%, (b) $V_{C.Agg.}/V_C$=50%

4. CONCLUSION

Based on the research results, the following conclusions can be drawn:

- Slump and segregation of the concrete mixtures using the keramzit and polystyrene aggregate significantly increased when the flow of mortar was ≥ 21 cm.
- Concrete mixtures containing keramzit were well homogenous with segregation less than 10%. Simultaneously, concrete mixtures consisting of polystyrene foam were fair well homogenous with segregation less than 25% when their slump less than 10 cm.
- With 40% and 50% content of aggregates, the density of dried concrete specimens using keramzit and polystyrene foam were in the range of 1440-1500 kg/m^3 and 1170-1310 kg/m^3 respectively.
- Only the concrete with 40% content of keramzit could be classified as structural lightweight concrete with compressive strength higher than 17 MPa in according to ACI 213R-14.

5. ACKNOWLEDGMENTS

The author sincerely thanks the Laboratory for Testing and Studying of Building Materials at National University of Civil Engineering and student group Giap Thi Huyen and Dao Viet Hoang helping to conduct the experiments.

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