AN EXPERIMENTAL STUDY ON THE MECHANICAL PROPERTIES OF HIGH STRENGTH LIGHTWEIGHT AGGREGATE CONCRETE

DANG THUY-CHI[1], PHAM DUY-HUU[2], ERIC GARCIA-DIAZ[3]
[1]Dr, [2]Prof, Faculty of Construction Engineering
University of Transport and Communications, Hanoi, Vietnam
[3]Prof, Ales Mining Materials Center, University of Mining, Ales, France
Corresponding author's email: thuychi.dang@utc.edu.vn

Summary: *In Vietnam, lightweight aggregate concrete (density lower than 2000 kg/m^3) having compressive strength in range of 20-30 MPa is applied for insulation structures such as panels, partitions, ceilings. However, high strength lightweight aggregate concrete (HSLWAC) with compressive strength of 40-60 MPa has not been studied and applied yet. This paper presents experimental studies on mechanical properties of HSLWAC based on expanded clay aggregates. Splitting strength, compressive strength, and rupture modulus of HSLWAC were investigated. The experimental results show the compressive strength of HSLWAC could reach 60 MPa with a corresponding density of less than 2000 kg/m^3. The relationships between splitting strength and compressive strength, rupture modulus and compressive strength of HSLWAC were established and compared with normal concrete.*

Key words: *high strength lightweight aggregate concrete, splitting tensile strength, modulus of rupture, mechanical properties*

I. INTRODUCTION

Traditional concrete is the type of material with a high density (about 2200 - 2600 kg/m3), depending on the type and amount of used aggregates. In the world, lightweight concrete with high compressive strength (more than 40 MPa) has been studied and developed since the 70s of the last century. Some great lightweight concrete structures were built in the late 1990s. Examples were Stolma Bridge built in 1998 in Norway (Figure 1), Bank of America Building, in North Carolina, America (1998) and Wellington Stadium, in New Zealand (1998). In fact, the mechanical properties of HSLWAC was studied since the 1990s. However, there are apparently contradictory results, which could be related to the different types of aggregate and strength levels of the lightweight aggregate concrete.

Figure 1. *Stolma Bridge (Norway)*

In Vietnam, lightweight aggregate concrete has begun to be interested, manufactured and applied for insulation structures such as panels, partitions, ceilings. Because of their limited strength, in our country lightweight aggregate concretes have not been applied in the structure with high load. The studies on lightweight aggregates were conducted by Nguyen Dinh Nghi et al. (1995) [1], Nguyen Van Chanh, Le Phuc Lam (2005) [2]. In 2001, the first study of the expanded clay lightweight concrete was carried out by Nguyen Van Dinh [3]. The author studied the influence of properties and gradation of the expanded clay lightweitght aggregate on most properties of lightweight concrete with compressive strength of 15-20 MPa. At the same time, Nguyen Tien Dinh, Nguyen Dang Do (2001) [4] investigated the physical and mechanical properties of structural lightweight concrete having the compressive strength of 15-30 MPa and density of 1600-1800 kg/m3. Recently, Nguyen Duy Hieu (2009) [5] have studied the structural LWAC with high slump. The research analyzed the workability and mechanical properties of expanded clay lightweight concrete with compressive strength of 36-38 MPa.

The purpose of this study is to understand the limits of HSLWAC having a strength up to 60 MPa for the first time in Vietnam, the difference in mechanical properties between lightweight and normal concrete with the same compressive strength. Moreover, these features can be used for the design of reinforced concrete structures.

II. EXPERIMENTAL PROGRAM

2.1. Materials

- Lightweight aggregate: expanded clay lightweight aggregate was imported from China (figure 2). The physic and mechanical properties of used expanded lightweight aggregate is presented in the table 1.

Table 1. *Properties of lightweight aggregate*

No	Properties	Values
1	Dimension, mm	5-20
2	Bulk density, g/cm^3	0,73
3	Dry density, g/cm^3	1,27
4	Saturated density, g/cm^3	1,34
5	Particle density, g/cm^3	1,38
6	Voids, %	0,43
7	Water absorption for 24h, %	6,15
8	Crushing strength, MPa	4,81

Figure 2. *Lightweight aggregates*

- Fine aggregate was the golden natural sand from Red river, the properties according to TCVN 7570-2006 standard [6].

- Cement used in this study was PC40 (Portland cement), the properties meets the requirements according to TCVN 2682-2009 [7].

- Silica fume and superplasticizer were used for reaching the requirements of high strength concrete.

2.2. Experimental program

This study provides some information of compressive strength, modulus of rupture and splitting tensile strength of LWAC having the 28-days strength up to 60 MPa and the density less than 2000 kg/m^3. The number of samples of test was summarized in table 2.

Table 2. *Experimental program of HSLWAC mechanical properties*

No	Index	Samle dimension (mm)	Number of samples		
			LC40	LC50	LC60
1	Density	150x300	15	15	15
2	Compressive strength	150x300	15	15	15
3	Splitting tensile strength	150x300	6	6	6
4	Modulus of rupture	100x100x400	6	6	6

2.3. Mix proportions of HSLWAC

Three types of HSLWAC compositions having specified compressive strengths of 40, 50 and 60 MPa are designed and manufactured. The water/ binder (W/B) ratio was fixed at 0.24, while the lightweight aggregate volume varied from 0.28 to 0.42. Silica fume was used in the dosage of 10% as a replacement of cement (by weight). Dried lightweight aggregates were pre-mixed during 5’ with an amount of water equal to its 24h-water absorption. The compositions of the three types of concrete are presented in Table 3.

Table 3. *Mix proportion of LWAC*

Type of LWAC	LC60	LC50	LC40
W/B	0.24	0.24	0.24
Cement (kg)	587	587	587
Water (kg)	155	155	155
Sand (kg)	844	639	493
Lightweight aggregate (kg)	381	486	591
Silica fume (kg)	58.7	58.7	58.7
Superplasticizer (kg)	8,81	8,81	8,81
Water to moisten aggregate (kg)	23.41	29.89	36.36

III. RESULTS AND DISCUSSIONS

3.1. Compressive strength and density of HSLWAC

The density and compressive strength at 28 days of LWAC were determined according to standard ASTM C567-04 [8] and ASTM C39-01 [9].The compressive strengths vary from 44 to 77 MPa while the density of concrete change from 1675 to 2023 kg/m^3 (Table 4).

Table 4. *Compressive strength and density of HSLWAC*

Sample	Density (kg/m^3)	Comp. strength (MPa)	Sample	Density (kg/m^3)	Comp. strength (MPa)	Sample	Density (kg/m^3)	Com. strength (MPa)
LC60-1	1996	69.2	LC50-1	1865	57.5	LC40-1	1753	56.7
LC60-2	1957	70.6	LC50-2	1871	58.9	LC40-2	1693	50.6
LC60-3	2023	77.7	LC50-3	1918	60.0	LC40-3	1675	53.4
LC60-4	2016	63.0	LC50-4	1906	59.9	LC40-4	1739	47.2
LC60-5	2001	65.0	LC50-5	1871	60.3	LC40-5	1686	44.2
LC60-6	2011	65.7	LC50-6	1911	60.6	LC40-6	1679	49.5
LC60-7	2013	73.2	LC50-7	1932	59.9	LC40-7	1720	50.9
LC60-8	2001	70.7	LC50-8	1899	62.4	LC40-8	1702	49.4
LC60-9	2017	77.5	LC50-9	1927	60.7	LC40-9	1715	48.9
LC60-10	1995	64.5	LC50-10	1904	56.8	LC40-10	1746	51.7
LC60-11	2000	72.1	LC50-11	1897	60.1	LC40-11	1766	53.0
LC60-12	1951	68.2	LC50-12	1886	58.9	LC40-12	1731	47.8
LC60-13	1924	66.4	LC50-13	1871	59.2	LC40-13	1784	48.8
LC60-14	1998	69.2	LC50-14	1826	60.2	LC40-14	1828	49.8
LC60-15	1938	68.5	LC50-15	1871	60.7	LC40-15	1845	52.1

The average compressive strength of LC 40, 50 and 60 concrete were respectively 50.3; 59.7 and 69.4 MPa while the corresponding density were 1737, 1890 and 1989 kg/m^3.

Modification standard deviations of the compressive strength results were calculated according to ACI 318-2011 [10]. Average compressive strengths at 28 days, standard deviation and specified compressive strength of three types of LWAC were presented in table 5.

Table 5. *Characteristical compressive strength of HSLWAC*

Type of concrete	Average compressive strengths at 28 days (MPa)	Modification standard deviations (MPa)	Specified compressive strength (MPa)
LC40	50.3	3.42	45.7
LC50	59.7	1.57	57.5
LC60	69.4	5.08	62.6

The destructive line of concrete pass through the aggregate with all grades of concrete (Figure 3). This can be explained by the good bonding between aggregate and cement paste as well as the low strength of the porous aggregate.

Figure 3. *Destructive form of LWAC axial compressed test*

The results show that compressive strength up to 60 MPa can be achieved even with the use of lightweight and porous aggregates for the first time in Vietnam.

3.2. Spliting tensile strength and modulus of rupture of HSLWAC

Splitting tensile strength and modulus of rupture of LWAC are determined in accordance with ASTM C496-04 [11] and ASTM C78-02 [12]. Observing the specimen after the splitting test (figure 4), the results show that the failure surface crossed the aggregates in LWAC, showing that the tensile strength is governed by LWA. Thus, it can be predicted that the splitting tensile strength of LWAC in the study would be lower than that of conventional concrete with the same compressive strength.

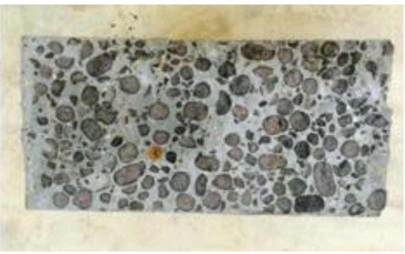

Figure 4. *LWAC specimen aftersplitting tensile strength test*

Figure 5 compares the splitting tensile strength of the LWAC and that of the normal concrete proposed by Carrasquillo, 1981 [13]. As can be seen from the figure, the splitting tensile strength of the lightweight aggregate concrete is lower than that of the limestone concrete and its average value was only 0.88 of that of high strength concrete having the same compressive strength. The relationship between splitting tensile strength f_{ct} and compressive strength f_c can be described by the following equation:

$$f_{ct} = 0{,}23 \sqrt[3]{f_c^2}$$

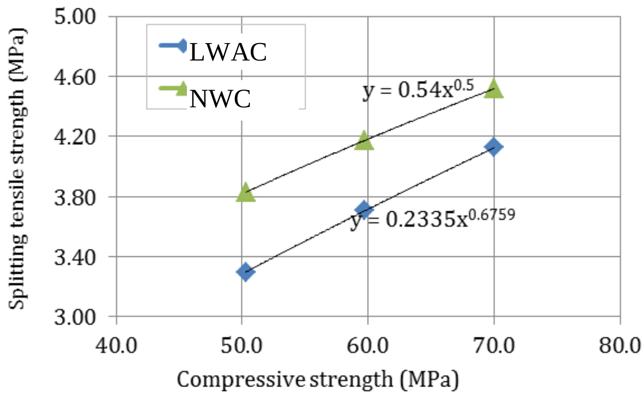

Figure 5. *Relationship between splitting tensile and compressive strength of concrete*

A comparison between the results of the study and other authors is shown in Figure 6. Except the expression of Zhang and Gjorv, 1991 [14] gives higher values, the difference between the formulas and other references is not significant.

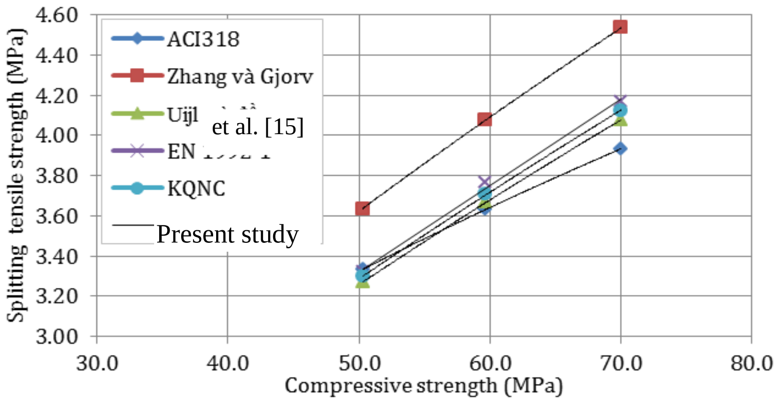

Figure 6. *Relationship between LWAC splitting tensile and compressive strength of the study and references*

Figure 7 shows the relationship between modulus of rupture and compressive strength for the LWAC also compared to that of the limestone concrete reported by Carrasquillo [13]. As for the splitting strength, the flexural tensile strength was also lower than that of the limestone concrete and its average value was only 0.73 of that of high strength concrete having the same compressive strength. This may be attributed to the influence of the weaker aggregate, as previously discussed.

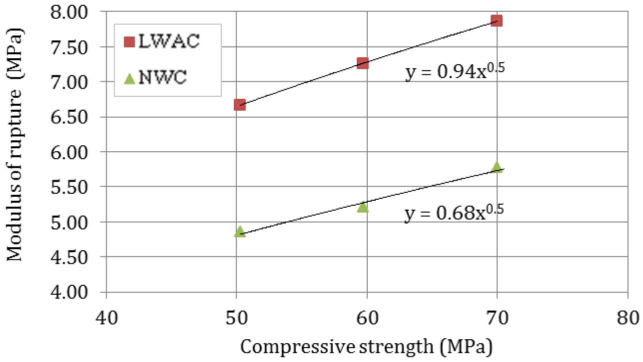

Figure 7. *Relationshipbetween modulus of rupture and compressive strength of the concrete*

Figure 8 shows a comparison of the modulus of rupture of the study and other authors. As can be seen from the figure, there is a strong correlation between the results of the study and the expression of Bogas and Nogueira [16]. However, these results are also 30% higher than the values calculated as per ACI 318-2011. For the lightweight aggregate concrete used in this study, the relationship between the modulus of rupture f_r and the compressive strength f_c can be estimated by the following equation which is similar to the expression proposed by Bogas and Nogueira [16]:

$$f_r = 0,68\sqrt{f_c}$$

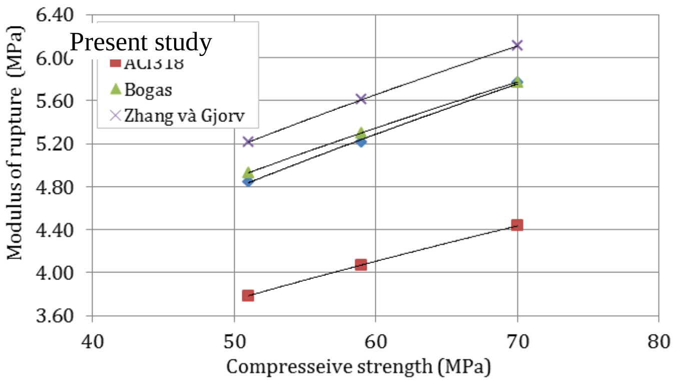

Figure 8. *Relationship between LWAC modulus of rupture and compressive strength of the study and references (right)*

III. CONCLUSION

Based on the experimental study and the reviewed literature, some conclusions can be drawn as follow

1. The 28-day compressive strength of the lightweight concrete reached up to more than 60 MPa, even with the bulk density less than 2000 kg/m^3.
2. The splitting tensile strength increases from 3.30 to 4.12 MPa when the compressive strength of the concrete increases from 50.3 to 69.4 MPa; the average tensile strength is 0.88 of that of the normal weight concrete with the same compressive strength.

3. The formula for calculating the splitting tensile strength of LWAC recommended by the study is strong correlated with ACI 318-2011 and EN 1992-1-1-2004 expressions.
4. The modulus of rupture of LWAC augments from 4.85 to 5.77 MPa when the compressive strength of the concrete increases from 50.3 to 69.4 MPa; the average value is 0.73 of that of normal weight concrete with equal strength. Study results are higher than ACI 318-2011 in case of modulus of rupture.

References

[1] *Nguyen Dinh Nghi*, “Research on production technology of lightweight expanded clay aggregate and lightweight expanded clay aggregate concrete”, Report on the results of scientific research, code RD 94-30 Ministry of Construction, 1995 (in vietnamese).

[2] *Nguyen Van Chanh, Le Phuc Lam*, “Study on manufacturing technology of expanded clay aggregate for application of lightweight materials", New Technology Conference, Ho Chi Minh City, 2005 (in vietnamese).

[3] *Nguyen Van Dinh*, Research on manufacture of lightweight, porous aggregate concrete, PhD thesis, University of Civil Engineering, Hanoi, 2001 (in vietnamese).

[4] *Nguyen Tien Dich, Nguyen Dang Do*, “Research on the using of lightweight materials for houses and works”, Report on the results results of scientific research, code number RDN 06-01, Ministry of Construction, 2001 (in vietnamese).

[5] *Nguyen Duy Hieu*, Study on the manufacture of structural lightweight concrete with high consistency, PhD thesis, University of Civil Engineering, Hanoi, 2009 (in vietnamese).

[6] *Ministry of Science and Technology*, TCVN 7570, Aggregates for concrete and mortar - Standard Specification, 2006 (in vietnamese).

[7] *Ministry of Science and Technology*, TCVN 2682, Portland cement - Standard Specification, 2009 (in vietnamese).

[8] *American Society for Testing and Materials*, ASTM C567, Standard Test Method for Determining Density of Structural Lightweight Concrete, 2004.

[9] *American Society for Testing and Materials*, ASTM C39, Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens, 2001.

[10] *American Concrete Institute*, ACI 318, Building Code Requirements for Structural Concrete and Commentary, 2011.

[11] *American Society for Testing and Materials*, ASTM C496, Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens, 2004.

[12] *American Society for Testing and Materials*, ASTM C78, Standard Test Method for Flexural Strength of Concrete, 2012.

[13] *R. L. Carrasquillo, A. H. Nilson, F. O. Slate*, "Properties of High Strength Concrete Subject to Short-Term Loads". ACI Journal, V. 78, No. 3: 171-178, 1981.

[14] *MH. Zhang, O. E. Gjorv*, "Mechanical properties of high-strength lightweight concrete", ACI Materials Journal. 88(2): 150-158, 1991.

[15] *J. A. Uijl et al*, Splitting behaviour of lightweight concrete.” Proc. of Internat. Symp. on structural lightweight Aggregate Concrete, Sandefjord, Norway: 154-163, 1995.

[16] *J. A. Bogas, R. Nogueira*, "Tensile Strength of Structural Expanded Clay Lightweight Concrete Subjected to Different Curing Conditions". KSCE Journal of Civil Engineering: 1780-1791, 2014♦