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APPLICATION OF PUMICE AGGREGATE IN STRUCTURAL LIGHTWEIGHT CONCRETE

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ABSTRACT

Lightweight aggregate concretes are widely incorporated in construction and development. This study, presents an experimental investigation on the properties of volcanic pumice lightweight aggregates concretes. To this end, two groups of lightweight concretes (lightweight coarse with natural fine aggregates concrete, and lightweight coarse and fine aggregates concrete) are built and the physical/mechanical and durability aspects of them are studied**.** The results of compressive strength, tensile strength and drying shrinkage show that these lightweight concretes meet the requirements of the structural lightweight concrete. Also, the cement content is recognized as a paramount parameter in the performance of lightweight aggregate concretes.

Keywords: Pumice; lightweight aggregate; lightweight concrete

1. INTRODUCTION

Lightweight concretes have been used as construction materials since the days of the Roman Empire. The earliest types of lightweight concrete were made by using Grecian and Italian pumice as lightweight aggregates. Developments in lightweight concrete production started in the 20th century. During the World Wars lightweight concrete was employed in the construction of ships and barges [1-3].

Nowadays, lightweight concretes are commonly used in precast and prestressed components. Specifically speaking, while lightweight concrete compels higher costs compared to normal weight concrete, structures may yet have lower costs as a result of the reductions in dead weight, foundation sizes and costs, and consumed reinforcing bars [4-8].

Common types of lightweight concretes are composed of lightweight aggregates, from natural sources (such as pumice, diatomite, scoria and tuff) and processed by-product or unprocessed porous materials (such as expanded clay, slag, slate and vermiculite); the former having comparatively lower costs [9-16].

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Pumice is one of the oldest lightweight aggregates used in constructions. During volcanic activation, the outflow of gases from cooling magma produces small hollow voids resulting in the porous structure of pumice. Hitherto, widespread researches have been devoted to the properties of pumice lightweight aggregate concrete and mix proportion effects [17-24]. These researches indicated that pumice lightweight aggregate concretes can satisfy the requirements of semi-lightweight structural concretes [17-21]. Compressive strengths (28-day) up to 55 MPa were achieved incorporating Turkish pumice aggregates [22]. Besides, the effectiveness of pumice lightweight aggregate concrete has been shown for structural wall panels [23].

This paper, aims to study the properties of volcanic pumice lightweight aggregate concretes. To this end, the physical/mechanical properties and durability of volcanic pumice lightweight aggregates concretes are investigated.

2. MATERIALS

In the following a brief description of materials used in the concretes is presented:

- *Aggregates*

The natural lightweight aggregates, i.e. coarse and fine aggregates, were obtained from a mine near mount Damavand in Iran. Also, natural fine aggregates were provided for making samples consisting lightweight coarse aggregates and natural fine aggregates.

Table 1: Chemical and other properties of lightweight aggregate and cement

	Lightweigh aggregate	**Cement**
Chemical analysis, %		
Calcium oxide (CaO)	3.7	61.9
Silica (SiO2)	60.2	21.2
Alumina (Al2O3)	17.3	4.2
Iron oxide (Fe2O3)	5.7	4.6
Magnesia (MgO)	1.2	3.4
Sodium oxide (Na2O)	2.9	0.6
Potassium oxide (K2O)	4.8	0.5
Sulfur trioxide (SO3)	0.1	1.79
Bogue potential compound composition, %		
Tri calcium silicate(C_3S)	-	52.74
Di calcium silicate(C_2S)	-	20.31
Tri calcium aluminate (C_3A)	-	3.35
Other properties		
3 days compressive strength, Kg/cm^2	-	223
7 days compressive strength, Kg/cm^2	-	306
28 days compressive strength, Kg/cm^2	-	414
Initial setting time, min	-	150
Final setting time, min	-	190
Specific surface, cm^2/gr	-	3296

- *Cement*

Type II Portland cement (according to ASTM C595) produced by Tehran Cement manufactory, was used in this investigation. The chemical and physical properties of this cement are presented in Table 1.

- *Water*

The municipal drinking water of Tehran was used.

3. LIGHTWEIGHT AGGREGATES PROPERTIES

A portfolio of tests were conducted on the lightweight aggregates in order to investigate their quality and physical properties, these are: chemical analysis, grading, determination of density and water absorption, strength, clay percent, and iron staining.

The chemical analysis results of aggregates are presented in Table 1. Based on macroscopic observations, aggregate samples contain mostly segments with light gray color (pumice, more than 90%) and thick gray and black segments (tuff, less than 10%).

Table 2: Aggregates properties

Type	water absorption (24 hours), %	SSD specific gravity (24 hours), Kg/m^3	water absorption (30 minutes), %	SSD specific gravity (30 minutes), Kg/m^3	Dry bulk density, Kg/m^3	Ten percent fines value, KN	Clay lumps, %
Lightweight fine aggregate	12	2135	9.5	2080	1114	-	0.59
Lightweight coarse aggregate	36.84	1409	30	1317	600	14.83	0.71
Natural fine aggregate	4.07	2500	3.63	2489	1592	-	0.22

The gradations of lightweight coarse and fine aggregates are presented in Figures 1 and 2, respectively. Also the grading of natural fine aggregates is shown in Figure 2. The aggregates grading show rather suitable correspondence with ASTM C330 standard grading curves.

Other physical and mechanical properties of aggregates, given in Table 3, reveal that the dry bulk density of lightweight aggregates is in the allowable range, however close to the maximum, for lightweight fine aggregates. As seen the percentage of clay lumps for lightweight coarse and fine aggregates are 1.05 and 0.59, respectively. These amounts comply with the ASTM C330 and C331 allowable limit (i.e. 2%). The ten percent value of lightweight coarse aggregates is in the ordinary range for lightweight aggregates.

The existence of iron compounds especially Fe_2O_3 in the lightweight aggregates' texture should be limited (ASTM C330 and C331) to prevent iron staining of concrete surface. To determinate this feature, visual classification of lightweight aggregates according to ASTM C641 was applied. Filter paper observations show a few yellowish stains which in comparison to the iron staining standard conditions are classified as very light stains, that is iron compounds are allowable.

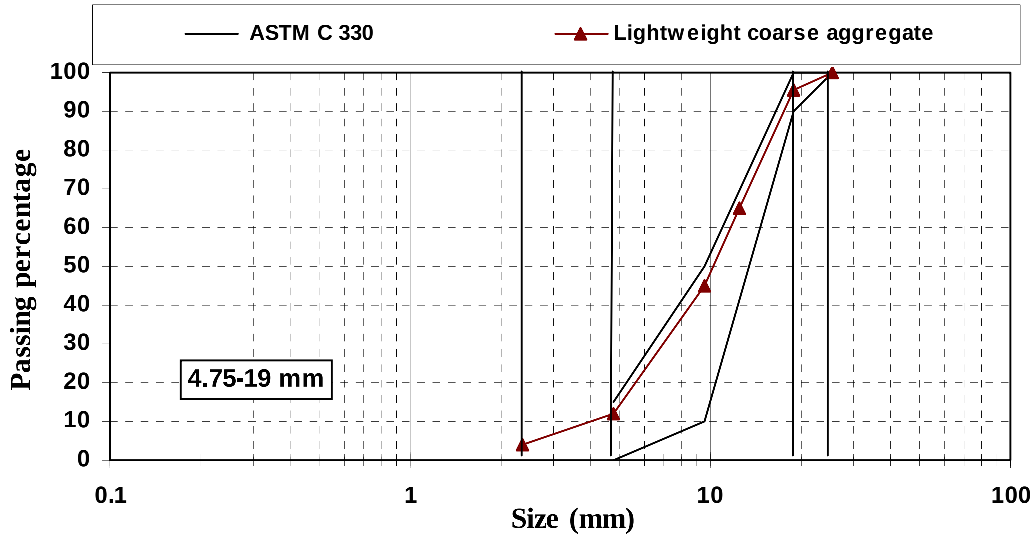

Figure 1. Lightweight coarse aggregate grading

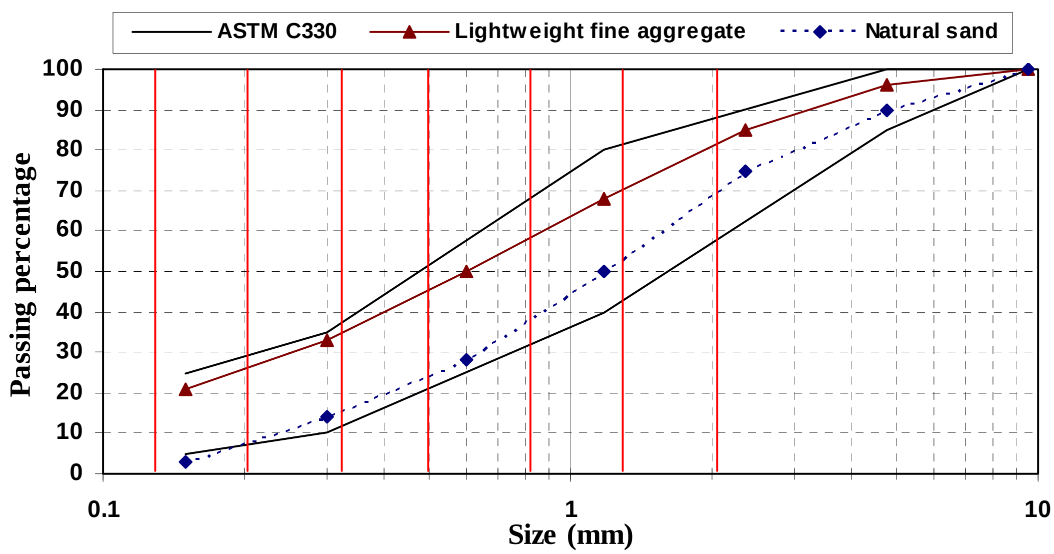

Figure 2. Lightweight fine aggregate and natural fine aggregate grading

Table 3: Mix designs of concretes

Identification	Cement content (Kg/m^3)	Free water content (Kg/m^3)	Coarse aggregate (Kg/m^3)	Fine aggregate (Kg/m^3)	w/c	Fresh concrete density (Kg/m^3)
lightweight coarse aggregates and natural fine aggregate concretes (LCNF)						
LCNF-1	500	183	407	803	0.37	1919
LCNF-2	420	175	457	819	0.42	1855
LCNF-3	350	165	411	922	0.46	1878
lightweight coarse and fine aggregates concretes (LCF)						
LCF-1	500	183	522	473	0.37	1666
LCF-2	420	175	561	465	0.42	1604
LCF-3	350	165	571	488	0.46	1607
Control Concrete (C)						
C	350	165	853	961	0.46	2357

4. MIX DESIGN

Two groups of lightweight concretes are built and compared with control concrete. The first group consists of concretes with lightweight coarse aggregates and natural fine aggregates and is termed LCNF. The second group comprises concretes with lightweight coarse and fine aggregates and is named LCF. The mix proportion of lightweight concretes and the control concrete are substantiated on the absolute volume method and presented in Table 4. To assess the effects of cement content on the properties of lightweight concretes, the mixtures are made by three cement contents of 500, 420 and 350 kg/m^3. For the mixes, slumps were nearly 50±10 mm and the lightweight coarse aggregate was restricted to 12.5 mm maximum size.

Table 4: Density of hardened concrete

Identification	Moisture density (Kg/m^3)	Oven dried density (Kg/m^3)	Equilibrium density (Kg/m^3)
LCNF-1	1950	1701	1826
LCNF-2	1848	1592	1735
LCNF-3	1920	1620	1762
LCF-1	1700	1364	1509
LCF-2	1641	1319	1472
LCF-3	1643	1292	1445
C	2351	2245	2283

5. RESULTS AND DISCUSSIONS

5.1 Density

The moisture, oven dried and equilibrium density of hardened concrete specimens, measured according to ASTM C567, are reported in Table 5. The equilibrium density of LCNF and LCF specimens varies from 1735 to 1830 kg/m^3 and 1440 to 1510 kg/m^3 respectively. The LCNF and LCF concretes are about 25 and 35 % lighter than control concrete, respectively. Besides, the oven dried density of these concretes is 30 and 40 % lower than control concrete. It can be concluded that the water absorption of these concrete are higher than control concrete.

5.2 Compressive strength

Figure 3 presents the results of compressive strength for 150×300 mm cylindrical specimens measured according to ASTM C39. For the LCNF and LCF concrete specimens the compressive strength varies from 20.4 to 30.2 MPa and 15.9 to 19.6 MPa respectively. The compressive strength of LCNF and LCF concretes are 20 to 40 % and 45 to 55 % lower than control concrete, respectively.

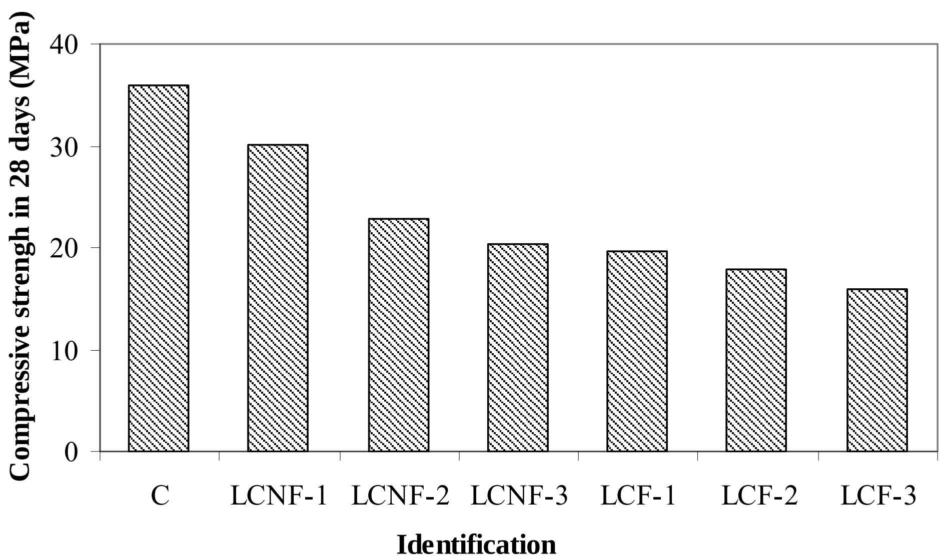

Figure 3. Compressive strength in 28 days

The strength and density requirements of LCNF-1, LCNF-2, LCF-1 and LCF-2 mixtures fulfill the structural lightweight concrete requirements, according to ASTM C330. This can be attributed to high amount of cement and low water/cement ratio of these mixes.

5.3 Tensile strength

The tensile strength test was implemented on 150×300 mm cylindrical specimens according to ASTM C496 and the results are shown in Figure 4. As seen, LCNF-1, LCNF-2 and LCF-1 mixtures comply with structural requirements.

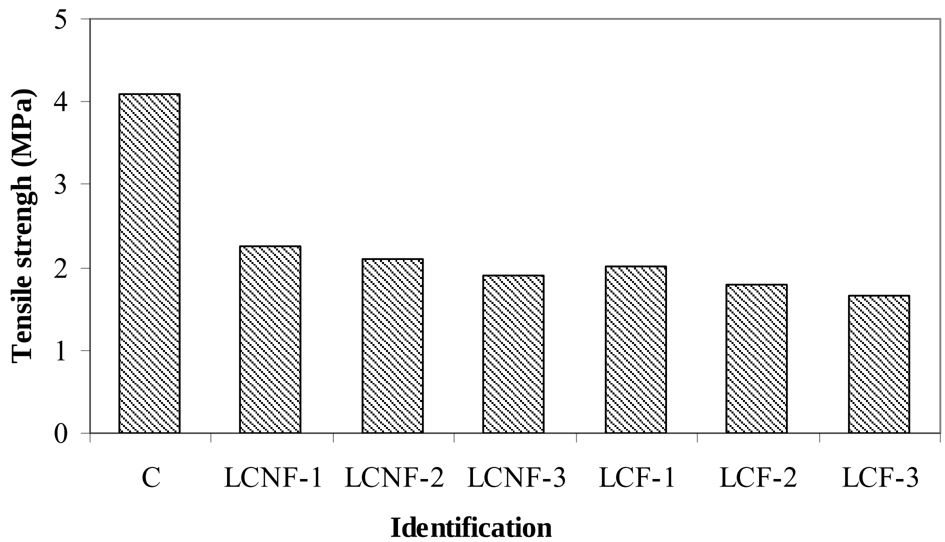

Figure 4. Tensile strength in 28 days

5.4 Drying shrinkage

The drying shrinkage was tested on 75×75×285 mm specimens as stated in ASTM C330 and the test results are shown in Figure 5.

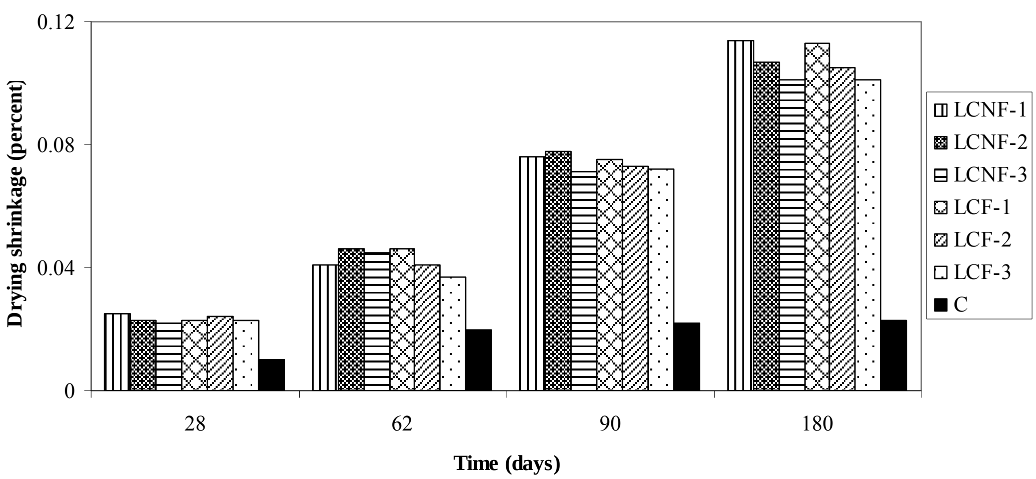

Figure 5. Drying shrinkage versus time

At initial ages, drying shrinkage of lightweight concrete is low and close to control concrete. Nevertheless, drying shrinkage increases with a higher rate compared to control concrete at later ages. This is attributable to the high water absorption of aggregates which delays the shrinkage time. When the absorbed water of aggregates dries out, shrinkage is experienced with a higher rate. On the other hand, the low modulus of elasticity of lightweight aggregates cause a higher drying shrinkage at later ages in comparison to control concrete.

5.5 Capillary absorption of water

The capillary water absorption, evaluated using 100 mm cubic specimens according to RILEM TC116-PCD, is shown in Figure 6. The capillary absorption of LCF-1, LCF-2, LCF-3, and LCNF-1 were close with LCF-1 showing the least capillary absorption.

The results reveal that cement content has an important role in capillary absorption. Furthermore, at the same cement content, LCF mixtures have less capillary absorption compared to LCNF mixtures. Since lightweight pumice aggregates have a porous structure, the absorbed water is stored in the lightweight aggregates instead of rising in the cement paste.

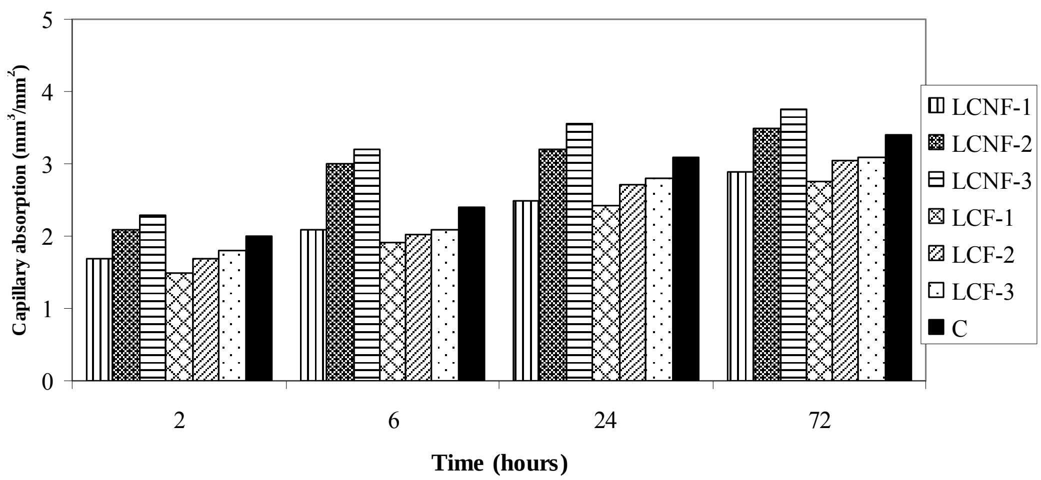

Figure 6. Capillary absorption of water versus time

5.6 Water absorption

Figure 7 illustrates the water absorption determined on the basis of BS 1881- Part 122. It can be observed that the water absorption of LCNF concrete specimens is less than LCF concrete specimens and much higher than control concrete. The high water content of lightweight aggregates at the SSD conditions, results in a higher water/cement ratio at the transition zone (between aggregates and paste) which in turn causes the concretes' higher permeability. These findings confirm Hossain's et al. [17-20] researches about the higher permeability of lightweight concretes compared to normal concretes.

5.7 Acid- soluble chloride content

In order to investigate the performance of concretes against chloride, concrete powders were made from specimens (at depth of 1 cm) and the acid- soluble chloride of samples were measured on the basis of ASTM C1152. The results are shown in Figure 8. It is observed that LCNF-1 and LCF-1 mixtures have the least acid- soluble chloride. Therefore, at higher cement content, the performance of specimens will be better under chloride attack conditions.

The results of the chloride ion penetration agree well with the water absorption results and Hossain's et al. [17-20] research about higher permeability of lightweight concretes.

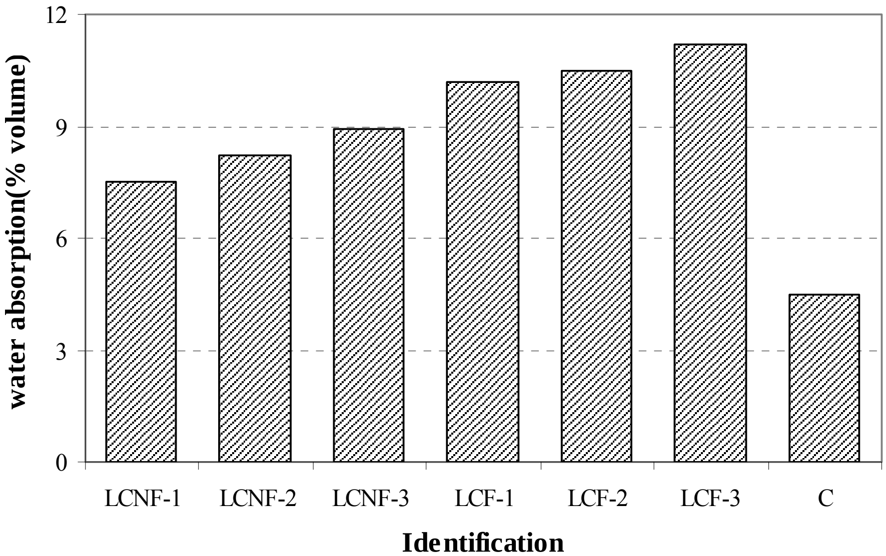

Figure 7. Water absorption in 24 hours

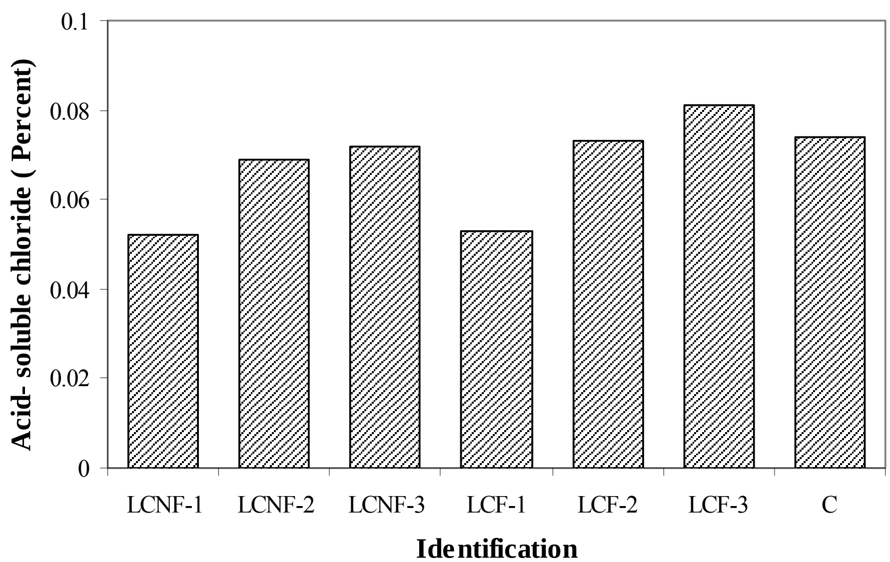

Figure 8. Acid- soluble chloride content

5.8 Sulfate expansion

Tests are conducted on 75×75×285 mm concrete prisms and the results are presented in Figure 9. The exposure solution used in this test contains 352 moles/m^3 of Na_2SO_4 (50 g/L). It can be observed that LCNF-1 and LCF-1 mixtures have better performance in the sulfate solution. Therefore, (1) the increase of cement content leads to reduced expansions and (2) at the same cement content the expansion of LCNF, LCF and control specimens are similar.

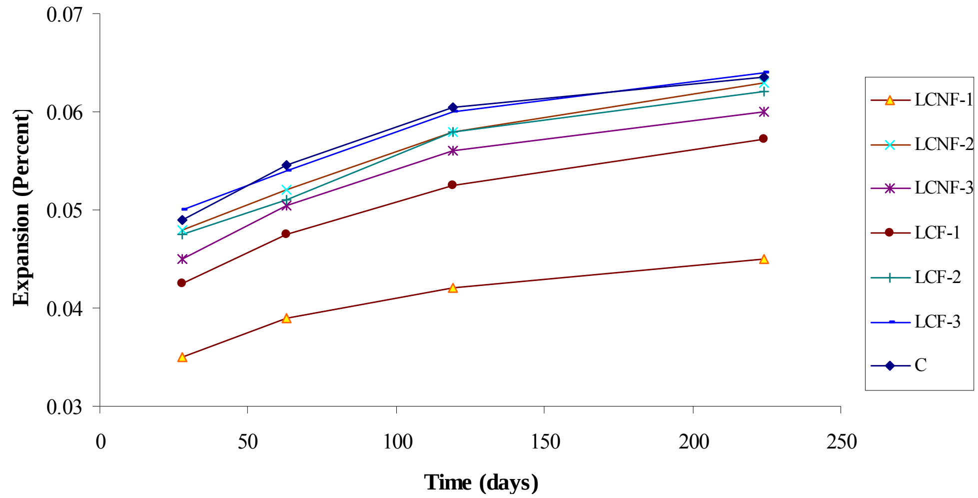

Figure 9. Expansion due to sulfate solution versus time

For specimens exposed to sulfate solution, the results of compressive strength are presented in Figure 10. LCNF-1 and LCF-1 mixtures have less reduction in the compressive strength compared to other mixtures. The basic reduction of compressive strength of specimens occurred after 119 days. This trend can be attributed to the filling of concrete's porosities by ettringate formations at early ages. Since the volume of reaction products exceed the pores' volume, micro cracks develop in the cement matrix which in turn reduces the compressive strength.

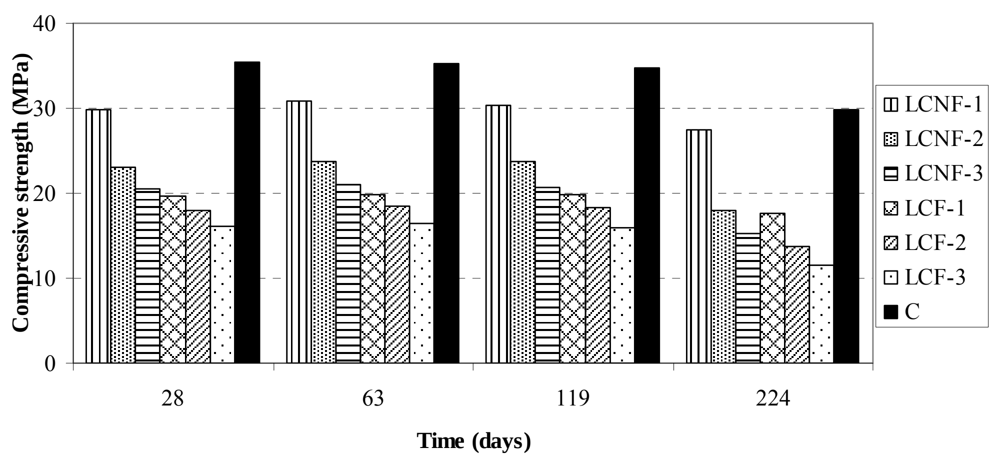

Figure 10. Variation of compressive strength in sulfate solution versus time

6. CONCLUSION

- The compressive strength of LCNF concretes is 20 to 40 % lower than control concrete, whereas they are about 30 % lighter than control concrete. The compressive strength of LCF concretes is about 50 % lower than control concrete, whereas they are about 40 % lighter than control concrete.

- Only mixes with high amount of cement, meet the strength requirements of structural lightweight concrete. Therefore, these lightweight aggregates are suitable for structural lightweight concrete construction.
- The cement content is a prominent factor in the physical/mechanical and durability properties of lightweight aggregate concretes. Increasing the cement content leads to a lower water/cement ratio in the transition zone; hence increases the mechanical and durability properties, and decreases capillary absorption, chloride content and sulfate expansion
- In lightweight aggregate concretes the rate of capillary absorption and the water absorption are not directly related. For these concretes the rate of capillary absorption and the water absorption are respectively lower and higher than control concrete.

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