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# Mechanical properties and freeze-thaw resistance of lightweight aggregate concrete using artificial clay aggregate

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**Abstract:** This work intends to make structural lightweight aggregate concrete by using artificial expanded clay aggregate with different replacement levels from normal coarse aggregate and improve it with a high-performance superplasticizer to increase its strength. The mechanical characteristics covered in the present work were compressive strength, flexural strength, and splitting tensile strength in addition to freezing and thawing resistance. Different densities were found for all mixes ranging between normal and lightweight concrete and that depends on the replacement of normal aggregate with lightweight aggregates. Mixes with replacement exceeding 25% give compressive strength less than 17 MPa and cannot be regarded as structural lightweight concrete. Modified mixes give higher values of mechanical properties, and also some non-structural lightweight concrete mixes were improved to structural lightweight concrete by using PC-superplasticizer in this study. The research also includes freezing and thawing cycles on reference mixes and lightweight mixes. Lightweight mixes give high durability against freeze-thaw cycles where the reduction in compressive strength was 6.2, 4.6, and 5.5% for 10% rep, 15% rep, and 20% rep mixes, respectively, compared with 32.2% reduction for reference mix.

**Keywords:** lightweight aggregate, lightweight concrete, flexural strength, freeze-thaw cycles

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## 1 Introduction

In the latest periods, further consideration has been focused on the improvement of lightweight concrete (LWC) where it pulls down the cost of building, facilitates construction, and had the improvement of being somewhat sustainable construction material [1]. LWC has different structural applications, such as pre-stressed and precast LWC elements, bridge piers, decks, and girders, especially when it exceeds 17 MPa and is used as structural members that are not highly loaded [2]. LWC may be created by using lightweight aggregate (LWA). Lightweight aggregate concrete (LWAC) is used in building construction as lightweight blocks and can reduce the dead load on foundations and structural members [3]. Clays when processed with heat will expand up to five or six times in volume as an outcome of gas liberation, as a result of which a porous clinker-like structure aggregate will be formed with a strong sintered layer on the outer surface [4]. Compared to various industrial raw ingredients, great technical features and various benefits can be obtained by using expanded clay aggregates which supplies the highest compressive strength among LWAs [5]. The artificial lightweight clay was studied in many types of research as LWA and its benefits were decrease in total weight of the building, decrease in costs, higher durability, and increase in fire resistance [6,7]. Aldakshe et al. [8] studied the production of LWC using pumice aggregate as a reference mix and 1, 3, 5, and 9% replacement (rep) of pumice aggregate by Boron waste (BA). The results showed an increment in compressive strength and splitting tensile strength of LWC when using BA for all replacement levels. In addition to that, an environmental benefit was achieved by using an industrial waste "Boron waste" as aggregate. Balamuralikrishnan and Saravanan [9] investigated the effect of partial replacement of Alccofine (AF) "which is an extremely fine material derived from waste glass" on compressive strength of cement mortar cubes. The results indicated that 10% AF by volume of cement was the best replacement level and gave the highest compressive strength of about 53 MPa. In some studies [10], waste thermo-stone was used as coarse LWA in concrete to produce LWC. In LWAC, compared to the mortar matrix, the LWA as a component may possess lower properties, so the characteristics of LWA are the important factors influencing the resulting concrete properties. Thus this study aims to evaluate LWAC properties by using Iranian artificial clay aggregate by using superplasticizer and also study the impact of freeze-thaw cycles (FTCs) on LWC made with this artificial clay aggregate because according to Mehta and Monteiro [11] several factors in LWA affect the property of concrete, such as types of aggregate, density, water content, environmental conditions, etc. One of the essential reasons of concrete deterioration is the exposure to several cycles of freezing and thawing which will affect the service life of the structures.

## 2 Experimental program

Figure 1 shows the experimental program details.

1) Materials used: in all mixes ordinary Portland cement type-I (Kar Factory-in Najaf city) was used, as coarse aggregate, using aggregates with a maximum size of 10 mm with grading shown in Table 1, and fine aggregate grading shown in Table 2 and it was confirming with Indian standards IS-383 [12]. Artificial expanded clay aggregate (lightweight) was also used as a percentage of coarse aggregate (replacement), some properties of this LWA are given in Table 3. Hyperplastic PC200 (formerly known as Flocrete PC200) meets the ASTM C494 [14], and Types A and G were used as high-performance superplasticizing admixture and its properties are given in Table 4.

**Table 1:** Grading and some properties of coarse aggregate

| Sieve size (mm) | % pass by weight | % passing, Indian standard specification |
|---|---|---|
| 20 | 100 | 100 |
| 10 | 100 | 85–100 |
| 5 | 18.3 | 0–20 |
| 2.36 | 3.6 | 0–5 |
| Property | — | — |
| Particle density (kg/m$^3$) | 1,589 | — |
| Los Angeles coefficient (LA%) | 24.8 | According to ASTM C131 [13] |

**Table 2:** Grading of fine aggregate

| Sieve size | % pass by weight | % passing, Indian standard specification, zone2 |
|---|---|---|
| 10 mm | 100 | 100 |
| 5 mm | 100 | 90–100 |
| 2.36 mm | 100 | 75–100 |
| 1.18 mm | 73.2 | 55–90 |
| 600 μm | 54.9 | 35–59 |
| 300 μm | 15.0 | 8–30 |
| 150 μm | 5.8 | 0–10 |

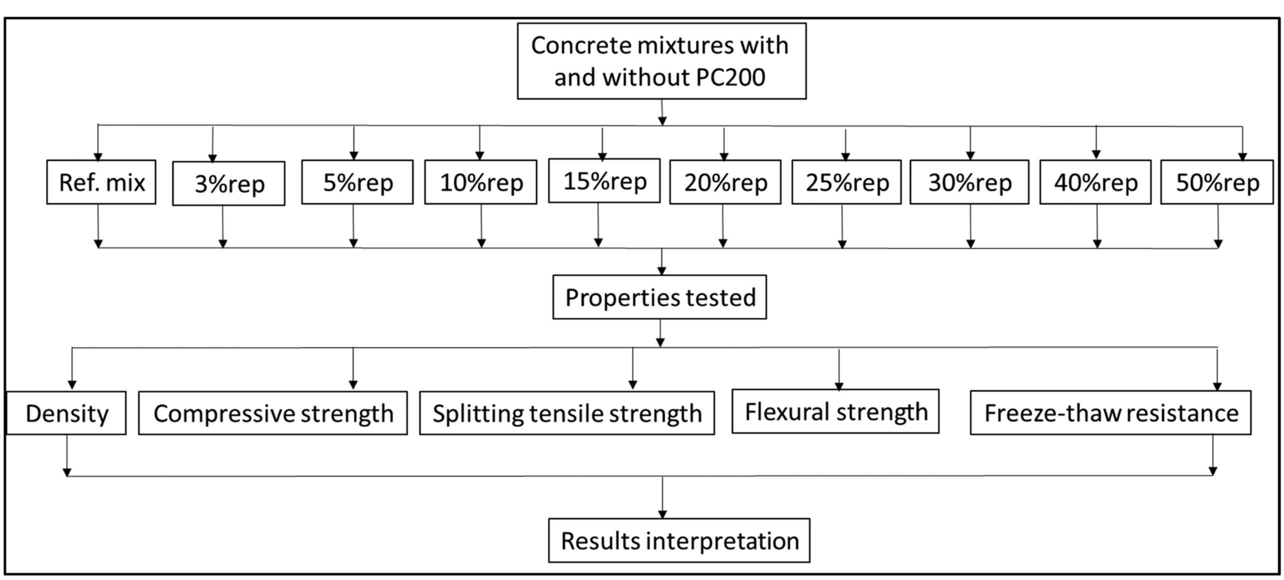


**Figure 1:** Flowchart of research methodology.

**Table 3:** Some properties of LWA (expanded clay)

| Property | Absorption (%) | Color | Maximum particle size (mm) | Density (g/cm$^3$) |
|---|---|---|---|---|
| Details | 40 | Gray | 10 | 0.29 |

**Table 4:** Some properties of PC-200 superplasticizer used in the study

| Property | Trading name | Chemical composition | Color | Specific gravity |
|---|---|---|---|---|
| Details | Hyperplast PC-200 | Polycarboxylate | Yellow-orange | 1.05 ± 0.02 at 25°C |

2) Mix proportions: reference mix with 1:1:1.2 was used (cement:sand:gravel), with a water to cement ratio of 0.42. Mixes with replacement of coarse aggregate with various levels of Iranian artificial clay aggregate of 3, 5, 10, 15, 20, 25, 30, 40, and 50% were improved with high-performance concrete superplasticizer type PC-200, with yellow-orange color. Figure 2 shows the artificial expanded clay aggregate and also the PC-200 superplasticizer. In this study, 1.5 L of superplasticizer was used for each 100 kg cement and water/cement ratio was decreased to 0.28 to maintain workability.

3) Specimens and tests: cubic molds with 10 cm × 10 cm × 10 cm was used for compressive strength test, while small beams of 10 cm × 10 cm × 40 cm were used for flexural strength tests as displayed in Figure 3. Three specimens for each test and for each mix was used and then the average value was determined. Moreover, the cubic specimens were weighed before conducting compressive strength test to find the density of concrete for all mixes. Compressive strength test was done by loading specimens after 28 days curing and subjecting to uniaxial load until failure.

A flexural strength test was done according to ASTM C78-02 [15] by using the third point loading test according to equation (1). Figure 4 shows the LWAC under different tests.

$$\mathrm{MR} = \frac{p \times l}{b \times d^2}, \tag{1}$$

where MR is the modulus of rupture (MPa). $p$ is the maximum load applied (N). $l$ is the distance between supports of the beam (mm). $b$ and $d$ are the width and depth of the beam (mm).

By using 100 mm × 200 mm cylinders, the tensile strength test was carried out and tested by splitting test method as shown in Figure 4 and according to equation (2).

$$F_t = \frac{2P}{\pi DL}, \tag{2}$$

**Figure 2:** Artificial expanded clay and PC-200 superplasticizer.

**Figure 3:** Some cubic concrete specimens with 3% replacement after casting and concrete beam with 10% replacement during mold open.

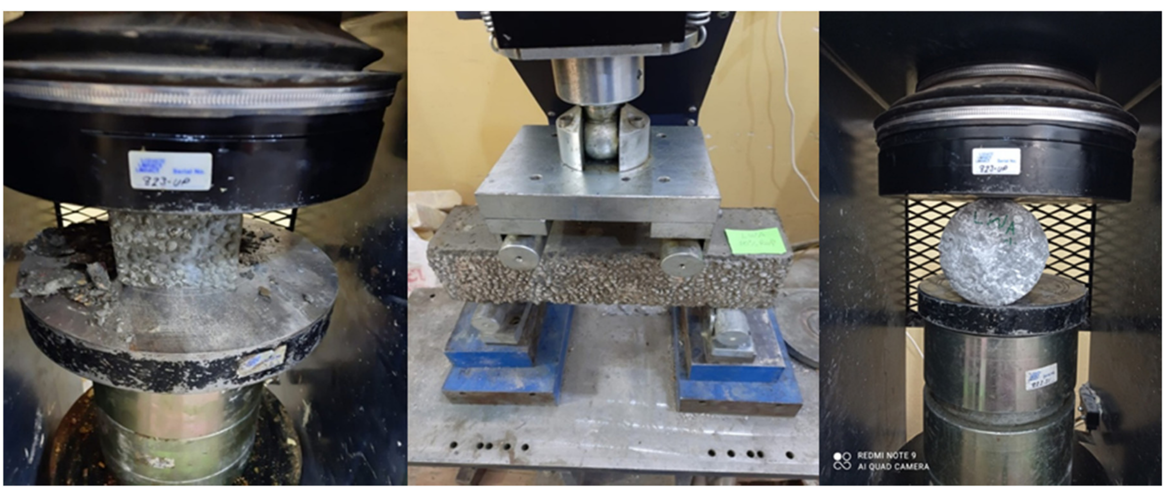


**Figure 4:** Some specimens under compression test, flexural test, and splitting test.

where $F_t$ is the splitting tensile strength (MPa). $P$ is the maximum load applied (N). $D$ and $L$ are the diameter and length of the cylinder (mm).

According to many researchers, several standards and methods were used to evaluate the freezing-thawing resistance of concrete such as ASTM C666 [16], European standard CEN/TR 15177 [17], and Chinese specification GB/T 50082-2009 [18]. In the present study, the test was done according to CEN/TS-12390-0 [19]. The freezing-thawing test was done by using cubic specimens tested in freezing room for 12 h in −18°C and 12 h in +20°C for 1 month and 2 months. Figure 5 shows the specimens during FTCs.

## 3 Results and discussions

Table 5 shows the mechanical properties of reference mixes and mixes with replacement with LWAs of different proportions from normal coarse aggregate and also densities for each mix. The forming of LWC begins from 20% LWA replacement, and this mix has a density of less than 2,000 $kg/m^3$. The concrete density decreased with the replacement of normal aggregate with LWA and also all mechanical properties decreased with the increase in the LWA replacement. This can be attributed to two reasons, the first is the low density of LWA which is porous and second reason is low strength of LWA compared to normal


**Figure 5:** Specimens under testing for FTCs.

**Table 6:** Mechanical properties of reference and LWAC specimens modified with PC-superplasticizer

| Mix | Compressive strength (MPa) | Tensile strength (MPa) | Flexural strength (MPa) | Density (kg/m$^3$) |
|---|---|---|---|---|
| 1:1:1.2 | 43.87 | 4.33 | 5.61 | 2,528 |
| 3% rep | 39.96 | 4.10 | 5.23 | 2,408 |
| 5% rep | 37.81 | 3.86 | 4.76 | 2,306 |
| 10% rep | 32.80 | 3.23 | 4.22 | 2,237 |
| 15% rep | 29.45 | 2.94 | 3.85 | 2,157 |
| 20% rep | 25.30 | 2.32 | 3.48 | 2,009 |
| 25% rep | 21.92 | 1.88 | 3.30 | 1,942 |
| 30% rep | 19.81 | 1.71 | 2.81 | 1,887 |
| 40% rep | 16.35 | 1.45 | 2.60 | 1,793 |
| 50% rep | 13.28 | 1.37 | 2.53 | 1,704 |

**Table 5:** Mechanical properties of reference and LWAC specimens

| Mix | Compressive strength, MPa | Tensile strength, MPa | Flexural strength, MPa | Density, kg/m$^3$ |
|---|---|---|---|---|
| 1:1:1.2 | 35.39 | 3.53 | 4.13 | 2,483 |
| 3% rep | 33.17 | 2.96 | 4.05 | 2,354 |
| 5% rep | 31.12 | 2.11 | 3.80 | 2,263 |
| 10% rep | 27.19 | 1.87 | 3.34 | 2,190 |
| 15% rep | 23.02 | 1.58 | 3.16 | 2,108 |
| 20% rep | 20.54 | 1.49 | 2.94 | 1,965 |
| 25% rep | 18.87 | 1.36 | 2.63 | 1,903 |
| 30% rep | 15.72 | 1.30 | 2.41 | 1,839 |
| 40% rep | 12.82 | 1.22 | 2.33 | 1,749 |
| 50% rep | 9.54 | 1.16 | 2.16 | 1,650 |

aggregate. Compressive strength of reference mix was found to be 35.4 MPa which then decreased to 9.54 MPa with 50% replacement. It can be seen from Table 5 that mixes with 30% replacement gave compressive strength less than 17 MPa which is a low value for structural LWC according to its definition.

Table 6 shows the same mixes but improved with high-performance superplasticizer PC-200. All mixes show higher values in compressive, tensile, and flexural strengths. 30% replacement mixes give 19.8 MPa by adding this admixture and it can be used as structural LWC.

Mixes with 40 and 50% replacement did not give structural LWC even when superplasticizer was added. Their compressive strength was still lower than 17 MPa and this may be due to the higher replacement level of coarse aggregate for these mixes. Figures 6–8 show the relationship between replacement of normal aggregate with LWA and compressive, tensile, and flexural strength, respectively. Figures 9–11 show the comparison between normal mixes and modified mixes (with PC-200 superplasticizer) for compressive, tensile, and flexural strengths.

Table 7 shows the effect of the FTC on the compressive strength of mixes. The reduction in strength of


**Figure 6:** Relationship between % replacement of normal aggregate with LWA and compressive strength without PC-superplasticizer.

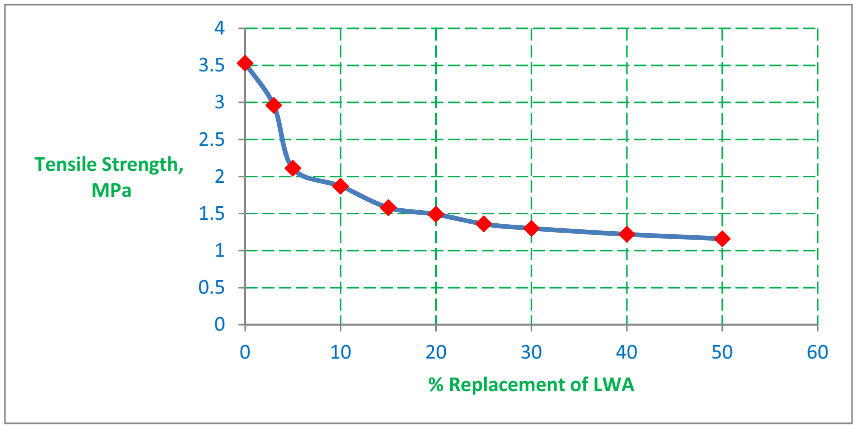


**Figure 7:** Relationship between % replacement of normal aggregate with LWA and tensile strength without PC-superplasticizer.

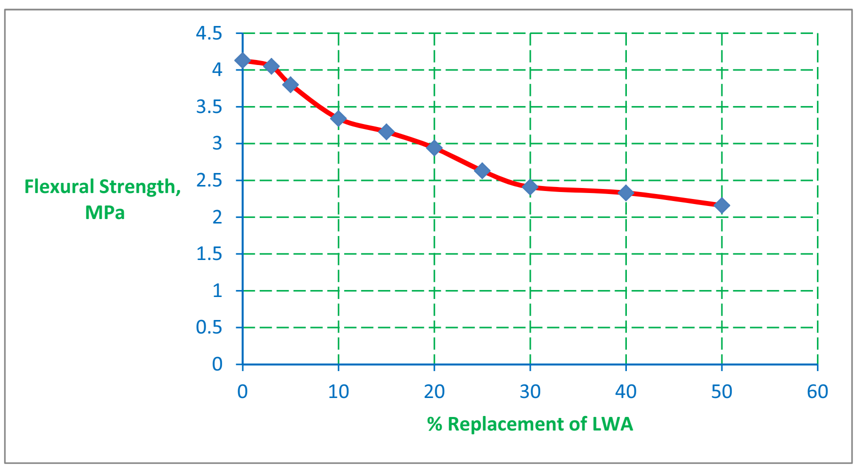


**Figure 8:** Relationship between % replacement of normal aggregate with LWA and flexural strength without PC-superplasticizer.

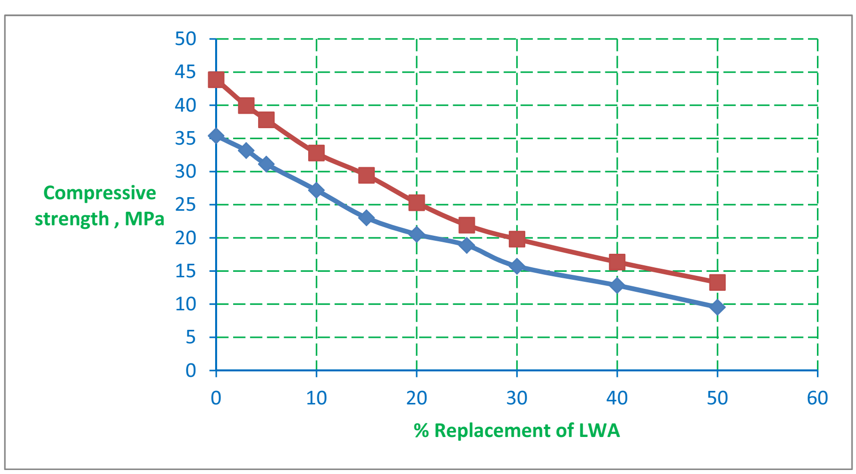


**Figure 9:** Relationship between % replacement of normal aggregate with LWA and compressive strength for normal mixes (lower curve) and modified mixes (upper curve).

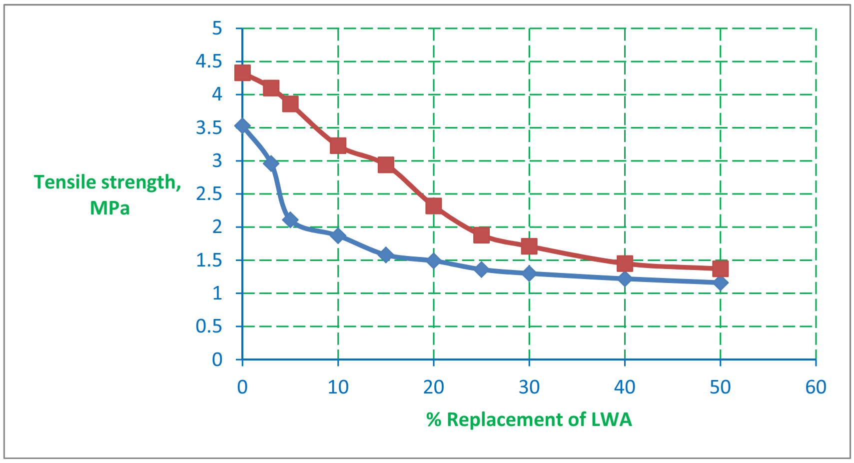


**Figure 10:** Relationship between % replacement of normal aggregate with LWA and tensile strength for normal mixes (lower curve) and modified mixes (upper curve).

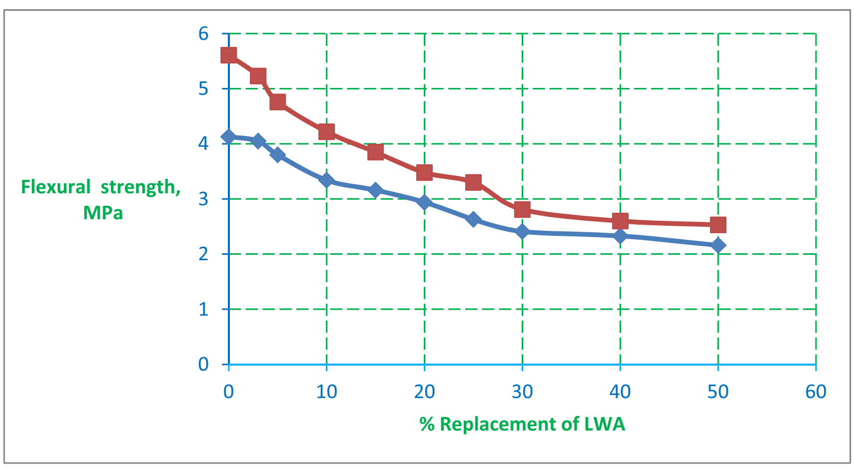


**Figure 11:** Relationship between % replacement of normal aggregate with LWA and flexural strength for normal mixes (lower curve) and modified mixes (upper curve).

**Table 7:** Compressive strength after FTCs

| Mix | Compressive strength before FTC (MPa) | Compressive strength after 1 month FTC (MPa) | Compressive strength after 2 months FTC (MPa) | Reduction in strength after 2 months (%) |
|---|---|---|---|---|
| 1:1:1.2 | 43.87 | 35.31 | 29.70 | 32.2 |
| 3% rep | 39.96 | 36.65 | 35.12 | 12.1 |
| 5% rep | 37.81 | 35.20 | 33.58 | 11.2 |
| 10% rep | 32.80 | 31.91 | 30.78 | 6.2 |
| 15% rep | 29.45 | 28.54 | 28.10 | 4.6 |
| 20% rep | 25.30 | 24.65 | 23.91 | 5.5 |
| 25% rep | 21.92 | 21.50 | 20.78 | 5.2 |
| 30% rep | 19.81 | 19.17 | 18.86 | 4.7 |
| 40% rep | 16.35 | 16.10 | 15.91 | 2.7 |
| 50% rep | 13.28 | 13.04 | 12.89 | 2.9 |

reference mixes after 2 months exposure was very high (about 32%). This may be due to that the micro-cracks were beginning to grow inside concrete during FTCs due to frost expansion. On the other hand, the reduction in strength decreases in LWC mixes as shown in Table 7 and this could be attributed to the reduction in the number of harmless pores due to high dosage of superplasticizer, so the pressure due to freezing may be valuably reduced. In addition to that, this performance may be interpreted as follows: the hydraulic pressure that resulted from frost may be released because the presence of voids in LWA can play a very important role as "expansion chambers" that will dissipate the pressure; therefore, lightweight mixes show higher durability to withstand cycles of freezing and thawing in this study and this was also observed by Bogas [20], Polat et al. [21], and Thienel et al. [22].

## 4 Conclusion

1- LWAC was achieved by using Iranian artificial clay as coarse aggregate in this study.
2- Structural lightweight with compressive strength exceeding 17 MPa was achieved in 3–25% replacements, more than 25% replacement gave compressive strength of less than 17 MPa.
3- Mixes can be improved by using PC-superplasticizer and achieving structural lightweight until 30% replacement.
4- Higher durability for FTCs was achieved by using artificial lightweight clay as coarse aggregate compared to normal aggregate, where the reduction in compressive strength after 2 months of FTC ranged between 3 and 12%.

**Conflict of interest:** Authors state no conflict of interest.

**Data availability statement:** The most datasets generated and/or analyzed in this study are comprised in this submitted manuscript. The other datasets are available on reasonable request from the corresponding author with the attached information.

## References

[1] JiaHao L, Chin Lian F, Hejazi F, Azline N. Study of properties and strength of no-fines concrete. Sustain Civ Constr Eng Conf. 2019;357:1–13. doi: 10.1088/1755-1315/357/1/012009.
[2] Patil P, Sonar I, Shinde S. No-fines concrete. Int J Concr Technol. 2017;3(2):1–13. https://www.academia.edu/34990495/No_Fine_Concrete.
[3] Tekin R, Kotan T, Osmanson A, Brostow W, Gencel O, Gonzalo M. Properties of lightweight concrete blocks with waste zeolitic tuff. Mater Sci J. 2020;26(4):463–70. doi: 10.5755/j01.ms.26.4.22777.
[4] Ozguven A, Gunduz L. Examination of effective parameters for the production of expanded clay aggregate. Cem Concr Compos. 2012;34:781–7. doi: 10.1016/j.cemconcomp.2012.02.007.
[5] Rashad AM. Lightweight expanded clay aggregate as a building material – an overview. Constr Build Mater. 2018;170:757–75. doi: 10.1016/j.conbuildmat.2018.03.009.
[6] Banawair A. The strength of lightweight aggregate in concrete-a review. IOP Conference Series – Earth and Environmental Science; 2017. p. 1–5.
[7] Subandi R, Kusuma C, Asnan M. Artificial aggregate lightweight structural. Ann Chim Sci Mater. 2019;43(4):213–6. doi: 10.18280/acsm.430403.
[8] Aldakshe A, Çağlar H, Çağlar A, Avan Ç. The investigation of use as aggregate in lightweight concrete production of boron wastes. Civ Eng J. 2020;6(7):1328–35. doi: 10.28991/cej-2020-03091551.
[9] Balamuralikrishnan R, Saravanan J. Effect of addition of alccofine on the compressive strength of cement mortar cubes. Emerg Sci J. 2021;5(2):155–70. doi: 10.28991/esj-2021-01265.
[10] Tumadhir M. Effect of using recycled lightweight aggregate on properties of concrete. J Babylon Univ. 2015;3:1–10, https://www.iasj.net/iasj/download/5b482158ed80164b.
[11] Mehta P, Monteiro P. Concrete: microstructure, properties and materials. Third edn. USA: McGraw Hill; 2006.
[12] IS-383. Indian standards specifications for coarse and fine aggregates from natural sources for concrete, Second Revis. New Delhi: Bureau of Indian Standards; REFFIRMED 2002. p. 20.
[13] ASTM C131. Standard test method for resistance to degradation of small-size coarse aggregate by abrasion and impact in the Los Angeles machine. American Society for Testing and Materials; 2006. doi: 10.1520/C0131_C0131M-14.
[14] ASTM C 494-05. Standard specification for chemical admixtures for concrete. American Society for Testing and Materials; 2005.
[15] ASTM C666/C666M-03 Standard test method for resistance of concrete to rapid freezing and thawing. American Society for Testing and Materials; 2008. p. 6.
[16] ASTM C666/C666M-03. StTest method resistance concr rapid freez Thawing; 2008. p. 6.
[17] CEN/TR 15177. Testing the freeze-thaw resistance of concrete. Intern Struct Damage. European Standard; 2006. p. 34.
[18] GT/B 50082-2009. Standard for test methods of long-term performance and durability of ordinary concrete. Ministry of Housing and Urban-Rural Development of China; 2009.
[19] Vandewalle L, Beeidens A. Test methods comparative study of concrete resistance against freeze-thaw cycles described in CEN/TS-12390-9, ISO DIS-4846-2. Conference Paper; August 2009.
[20] Bogas JA. Characterization of structural concretes with expanded clay light aggregates. PhD thesis in Civil Engineering. Portugal: Institute Superior Technical (IST), University of Lisbon; 2011.

[21] Polat R, Demirboga R, Karakoç MB, Türkmen I. The influence of lightweight aggregate on the physico-mechanical properties of concrete exposed to Freeze-thaw cycles. Cold Reg Sci Technol. 2010;60(1):51–6. doi: 10.1016/j.coldregions.2009.08.010.

[22] Thienel C, Dohl FS, Feldrappe V. Freeze-thaw resistance of LWAC made without air-entraining agents. Second International Symposium on Structural Lightweight Aggregate Concrete. Kristiansand, Norway. 18–22 June 2000. p. 757–9.