Building Tomorrow's Society
Bâtir la Société de Demain

Fredericton, Canada
June 13 – June 16, 2018/ *Juin 13 – Juin 16, 2018*

INVESTIGATION OF STRUCTURAL PROPERTIES FOR LIGHTWEIGHT CONCRETE PRODUCED BY USING LOCAL LIGHTWEIGHT AGGREGATE CICOLITE AND EXPANDED

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Abstract: Due to the fact that concrete is the most widely used construction material in Saudi Arabia (SA) and the world which have heavy weight. Since the major component of concrete is the aggregate with variety of lightweight aggregate (LWA) types available in SA, this research comes to focus on the selection of the best LWA to produce lightweight concrete (LWC) through replacing of normal coarse aggregate by two lightweight materials are available in SA Expanded Perlite (EP) and Cicolite, by mixing different percentages starting from 50% to 100%. And investigate the mechanical properties thought laboratory experiments for different curing periods of 7, 28, and 90 days. The results indicate that 50% Cicolite replacement is the best replacement percentage for structural aspects of reduction in density 13.2% comparing with normal coarse aggregate (2150 kg/m3) and achievement percentage of design strength at 28 days is more than 31%. For non-structural aspects 100% of EP replacement is selected of density 1400 kg/m3 lower than normal mix by 43% with compressive strength of 13.7 MPa. Which will reduce structure own weight, reinforcement needed, cross-sections size, and materials used.

1 INTRODUCTION

Concrete is a material that literally forms the basis of our modern history. A concrete is by far the most widely used material today in construction of variable structures. Actually, it is hard to find any aspect of human life that has no direct or indirect relation with concrete. The various unique properties of concrete such as the mouldability, high compressive strength, availability of components, etc. make it distinct over many other construction materials. Moreover, the discovery of reinforcing techniques helps in enhancing its tensile strength. The cheapness, durability, and exclusive resistance to weather, fire, water and corrosion, make concrete a particularly suitable and unique material for diversified structural applications (Andaleeb 2005).

Structural lightweight concrete is an important, which offers a range of technical, economic and environmental-enhancing. It has many and diversified applications: multistory building floors and frames, curtain walls, shell roofs, folded plates, bridges, pre-stressed and pre-cast elements of all types and others. Structural lightweight aggregate concrete is generally used to reduce dead loads of structure. Also, the reduction of the dead loads of a construction results in a decrease in the cross-section of columns, beams and plates, thus reducing the load on the foundation. Tensile strength capacity, lower coefficient of thermal expansion and sound insulation characteristics due to air voids are advantages of structural lightweight aggregate concrete (Andaleeb 2005), (Dawood and Ramli 2008).

In most cases, the considerably higher cost of the lightweight concrete is offset by size reduction of structural elements, less reinforcing steel and reduced volume of concrete, resulting in lower overall cost. The structural lightweight concrete provides a higher fire-rated concrete structure, and also benefits from energy conservation considerations as it provides higher R-values of wall elements for improved insulation properties (NRMCA 2016).

1.1 Problem Statement

Most of the private, commercial and government buildings in Saudi Arabia are of less than six floors, and are built with conventional steel-reinforced concrete. Due to the heavy weight of the concrete, the load on the columns is high, which necessitates oversized columns, resulting in excessive use of steel and cement. This problem becomes prominent in a booming construction market as in Saudi Arabia. Since the major component that contributes to the weight of concrete is the aggregate, there is a need for light-weight aggregates. However, the mechanical properties of such light-weight structures should not be maintaining the Integrity of the Specifications be compromised. These issues demand for choosing suitable light-weight aggregates and detailed mechanical characterizations of the light-weight concrete.

1.2 Goal

The goal of this study is to reduce excessive load in buildings by using light-weight concrete produced by using light-weight local aggregate.

2 LITERATURE REVIEW

According ACI Committee 213 makes three divisions based on strength and unit weight as shown in Figure 1. Lightweight concretes can be divided into structural lightweight concretes and Ultra-lightweight concretes for non-structural purposes. Low-density, low-strength concrete used for isolation, and moderate-strength lightweight concrete used for concrete block and other applications where some useful strength is desirable, the last division is structural lightweight concretes (Neville 2010).

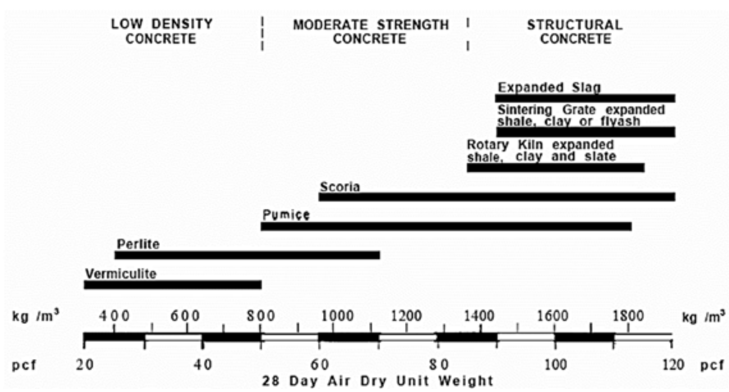

Figure 1: Typical ranges of air-dry densities of concretes made with various lightweight aggregates.

2.1 Types of Lightweight Aggregate

Lightweight aggregates According to ACI 213 are grouped into two types base on their source:

- Naturally occurred and unprocessed aggregates.
- Processed aggregates.

Table 1. shows the most common classification of aggregates based on bulk specific gravity (Satish and Berntsson 2003).

Table 1: Density classification of concrete aggregates.

Category	Unit Weight of Dry-rodded Aggregate (kg/m3)	Unit Weight of Concrete (kg/m3)	Typical Concrete Strengths (MPa)	Typical Applications
Ultra lightweight	<500	300-1100	<7	Non-Structural
Lightweight	500-800	1100-1600	7-14	Insulation
Structural Lightweight	650-1100	1450-1900	17-35	Structural
Normal weight	1100-1750	2100-2550	>35	Structural
Heavyweight	>2100	2900-6100	>35	Radiation Shielding

2.2 Natural Pozzolan (Cicolite)

Pozzolan is a siliceous or siliceous and aluminous material which possesses little or no cementations value, but which will in finely divided form and in the presence of water, react chemically with calcium hydroxide at ordinary temperature to form compounds possessing cementations properties, Pumice and Scoria also known as natural pozzolans (Mehta 1987). Natural pozzolans are classified by ASTM C 618 (AASHTO M 295) as Class N pozzolans.

2.3 Availability of Natural Pozzolan (Cicolite) in Saudi Arabia

Pozzolans are naturally-occurring pozzolans of volcanic origin. In Saudi Arabia "Aharat" (wide fields of volcanic lava rocks) see Figure 2. Aharat covers large areas of the western Arabian continental pier estimated by 180 thousand square kilometers and extends north in a wide belt intermittently from Yemen in the south to Syria in the north see Figure 3.

Figure 2: Aerial view of one of Aharat in west region in Saudi Arabia (SGS, 2016).

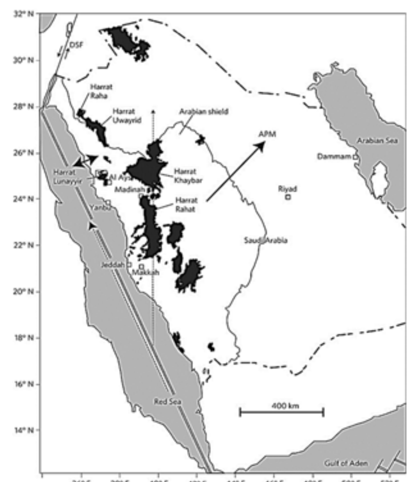

Figure 3: A Map showing the types and distribution and extensions of Aharat in the Kingdom of Saudi Arabia (Pallister et al. 2010).

2.4 Expanded Perlite

EP as example of processed aggregate, is a hydrated volcanic glass, commonly has a pearly. Upon rapid heating, perlite transforms into a cellular material of low bulk density. Generally, at temperatures in the range of 900 ºC to 1000 ºC, the resultant steam forms bubbles within the softened rock to produce a frothy-like structure. The formation of these bubbles allows perlite to expand up to 15-20 times of its original volume. This new material is referred to as EP. Because of its favorable physical and chemical characteristics, EP finds diverse utilization in various applications: for use as a lightweight aggregate in the construction industry (Satish and Berntsson 2003).

2.5 Production of perlite is Saudi Arabia

There are many factories in Saudi Arabia produce EP from the raw perlite which founded in many of Aharat (wide fields of volcanic lava rocks) in south and west regions of the kingdom. As example about these factories Saudi Perlite Ind. In Riyadh city consider as the main factor of perlite in Saudi Arabia, also CMCI (Construction Materials Chemical Industries) in first industry city in Dammam cite.

2.6 Previous Studies

(Chia and Zhang 2002) studied the water permeability and chloride penetrability of lightweight concrete (LWC) in comparison to that normal-weight concrete (NWC) with or without silica fume. Also, (Haque et al. 2004) studied the Strength and durability of lightweight concrete. By the specimens made with lightweight coarse aggregates and a dune sand. (Rossignolo et al. 2003) studied five mixtures made with selected Brazilian expended clay in order to produce LWAC for slim precast components. And (Dawood and Ramli 2008) they used the same marital (crushed clay brick) as coarse and fine lightweight aggregate to produce structural lightweight concretes. Also making of structural lightweight concrete was studied by (Yasar et al. 2003) with using of basaltic pumice (scoria) as aggregate and fly ash as mineral admixtures.

The suitability of using volcanic pumice (VP) as cement replacement material and as coarse aggregate in lightweight concrete production was investigated by (Anwar Hossain 2004). Tests were conducted on cement by replacing 0% to 25% of cement by weight and on concrete by replacing 0% to 100% of coarse aggregate by volume. Also, (Türkmen et al. 2006) measured the compressive strengths of concretes made up of mixtures of pumice aggregate (PA) of different ratios (25%, 50%, 75% and 100% pumice ratios were used instead of normal aggregate by volume) and with different cement dosage (200, 250, 350, 400 and 500 kg/m^3 cement dosages were used) and slumps (3 ± 1, 5 ± 1 and 7 ± 1 cm). (Mouli and Khelafi 2008) studied the using of Algeria Pozzolan as cement replacement only. Six concrete mixtures: one specimen with Portland cement (control) and five mixtures with 10%, 20%, 30%, 40%, and 50% of by Pozzolan were tested. Workability, density, compressive strength, splitting tensile strength, and flexural strength were determined after 3, 7, 28, 90 and 365 days. Their study found that the optimal percentage of using Pozzolan is 20% of the weight of cement which produced the highest strength. (Demirboğa et al. 2001) investigated the effects of silica fume (SF) and class C fly ash (FA) on the compressive strength of concretes made up of mixtures EP (EPA). SF and FA were added as replacement for cement by decreasing the cement weights in the ratios of 10%, 20%, and 30% by weight.

(Mesut Aşik 2006) studied the use of natural perlite aggregate by the use of perlite powder as a replacement of the cement. Six mixes were produced with different cement content and with or without perlite powder. Of cement content of 300 kg/m^3 and 500 kg/m^3 and water/cement ratios 0.49 and 0.35 respectively. Also, (Topçu and Işikdağ 2008) investigated the properties of concrete containing EP aggregate (EPA) considering cement types (CEM II 32.5R and CEM I 42.5R), dosages (300, 350 and 400) and replacement ratios (0, 15, 30, 45 and 60).

As summary of previous works reveals that the properties of lightweight concert are better than normal concrete in permeability, chloride penetrability, density, workability, acoustical and thermal insulating which has a good impact of economic and environmental aspects. However, it has less strength of compression. It found that previous studies used EP to produce lightweight concrete as cement or sand replacement and studied the influence of the such as Fly ash and Silica foam. And using Cicolite (natural Pozzolan, scoria, and volcanic pumice) as cement or cement and coarse aggregate replacements and studying the effect of adding mineral admixtures on the properties of concrete. However, no work was reported on the use of EP as coarse aggregate replacement for making lightweight concrete also there is lack in works reported the using of natural Pozzolan in Saudi Arabia and in the studying of its effects on concrete properties, despite having the great availability of both materials in the Kingdom. Accordingly, this research will focus on the use of EP and Cicolite to produce lightweight concrete in the Kingdom Saudi Arabia, with specific investigation on the effect of them as coarse aggregate replacement on the mechanical properties of concrete.

3 METHODOLOGY

3.1 Overview

The overall methodology is presented in Figure 4 shows the inputs, processes and the expected outputs.

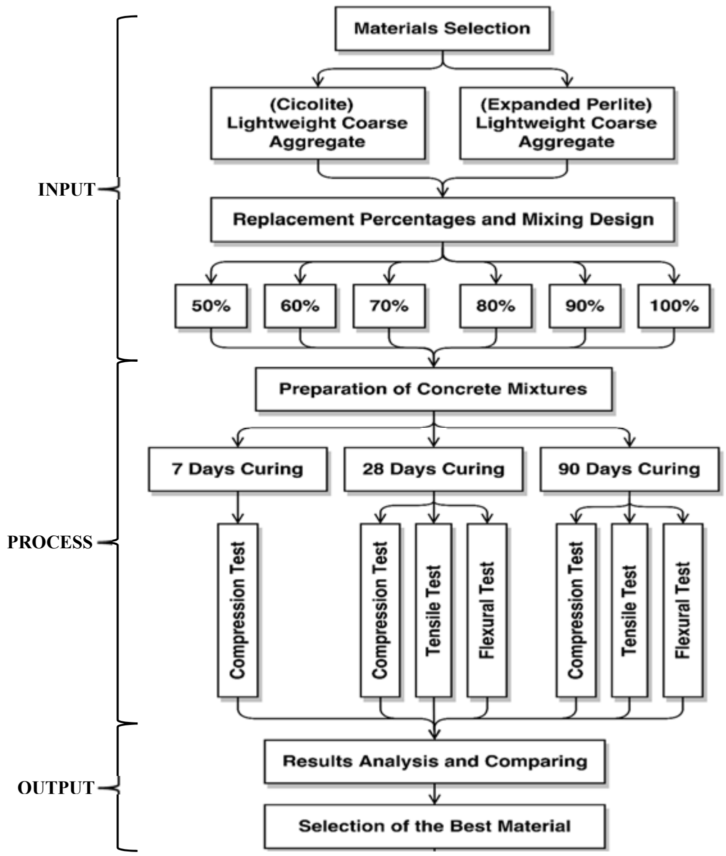

Figure 4: Methodology overview.

3.2 Materials

This research has 13 mixing percentages (One Normal Mix, 6 for EP and 6 for Cicolite) each percentage has 15 lager cylinder samples of 150x300mm, 2 small cylinder samples of 100x200mm and 6 large beam samples of 100x100x500mm. The materials used in the study are described as follows:

1. Cement

In this study ordinary Portland cement (Type I) is used as a binder material.

2. Coarse Aggregate

The coarse aggregate used in this research is from Riyadh road in eastern region of Saudi Arabia and will be 20mm + 10mm as normal aggregate and will use Cicolite of 10mm and EP as replacement of normal coarse aggregate with different percentages of lightweight aggregate see Figure 5.

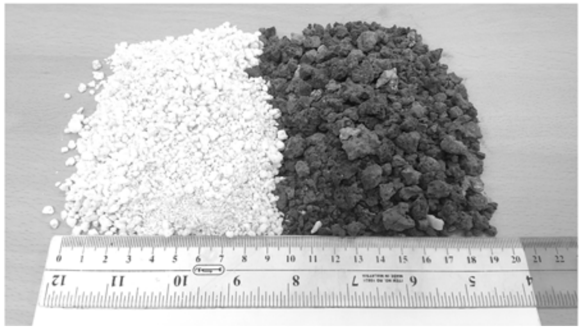

Figure 5: Lightweight coarse aggregate used Cicolite (right) and EP (left).

3. Fine Aggregate (dune sand)

From Dammam city in the in eastern region of Saudi Arabia. Figure 6. Shows grading curve of both coarse and fine aggregates.

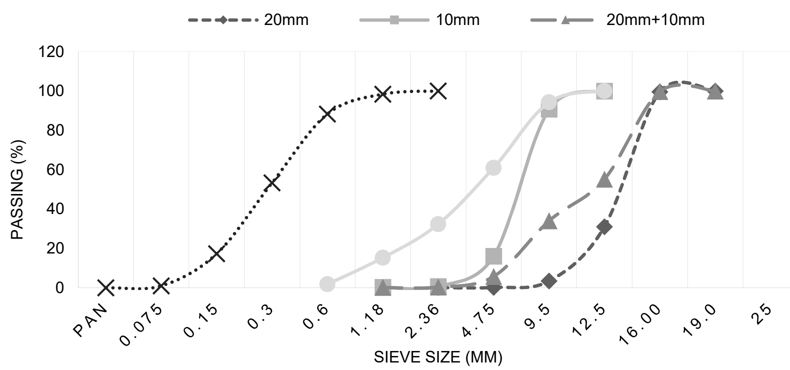

Figure 6: Grading curve of coarse and fine aggregates.

4. Water

The water for preparing and samples curing was potable water from the lab tap of pH rang 6.7 to 7.7.

5. Admixture

Use two types of chemical admixture Concrete Plasticizer and High-Performance Super-plasticizer for improving the workability and reducing the water needed in the mixing.

6. Mixing

An experimental investigation performed by developing standard design mix in factory which gives 28 MPa where 388 specimens of six different percentages both Cicolite and EP as following in Table 2.

Table 2: The percentages of normal and lightweight course aggregate in trial mixes.

Number of Trial	Normal Coarse Aggregate (%)	Lightweight Coarse Aggregate (%)
1st	50	50
2nd	40	60
3rd	30	70
4th	20	80
5th	10	90
6th	0	100

All other compositions of the mixture will be fixed (cement, water, Fine aggregate and admixture). Each percentage contain 4 trials enough to fill 15 cylinders molds, 2 small cylinders molds, 6 large beam molds and 3 small cubes. Where the total number of Trials are 52 trials. 21 specimens required for each percentage according to the type of test need see Figure 7.

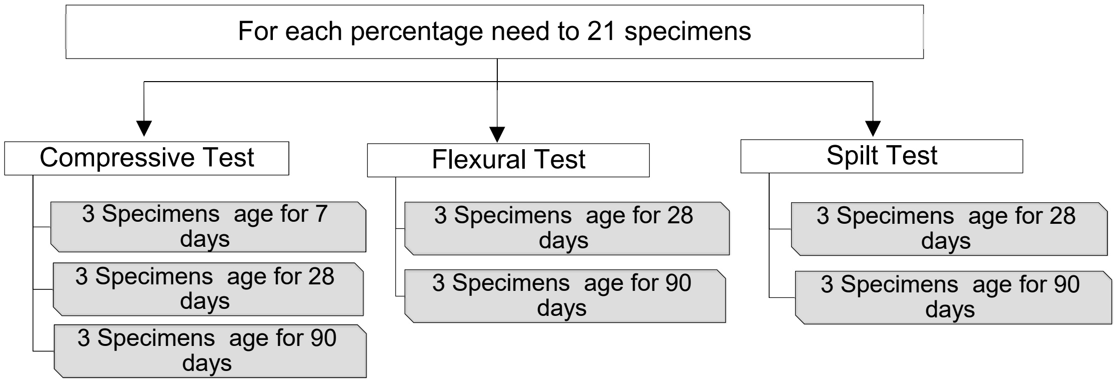

Figure 7: The number of specimens required for each percentage.

7. Trials Mix Design

All trial mixes will have fixed water to cement ratio (W/C = 0.40) with cement dosage of 410 kg/m^3 as explained previously. Base on the normal trial mix (control mix or base case). Next tables shown some trial mix details.

Table 3: Trial mix details of control mix.

Item Description	Unit	Trial Amount	Surface Moisture	Adjusted Trial Amount (0.04 m^3)	Actual Mix Amount (1 m^3)
Cement type I (OPC)	Kg	16.400		16.400	410.00
Water quantity	LTR	6.000		6.582	150.00
10mm Coarse Agg.	Kg	17.400	-2.00	17.052	435.00
20mm Coarse Agg.	Kg	26.000	-1.80	25.532	650.00
Sand (Fine Agg.)	Kg	29.200	0.80	29.434	730.00

Table 4: Trial mix details of 50% Cicolite replacement.

Item Description	Unit	Trial Amount	Surface Moisture	Adjusted Trial Amount (0.04 m^3)	Actual Mix Amount (1 m^3)
Cement type I (OPC)	Kg	16.400		16.400	410.00
Water quantity	LTR	6.000		7.307	150.00
10mm Coarse Agg.	Kg	8.600	-2.00	8.428	215.00
20mm Coarse Agg.	Kg	13.000	-1.80	12.766	325.00
10mm Cicolite	Kg	14.200	-8.00	13.064	355.00
Sand (Fine Agg.)	Kg	29.400	0.80	29.635	735.00

Table 5: Trial mix details of 50% Expanded Perlite replacement.

Item Description	Unit	Trial Amount	Surface Moisture	Adjusted Trial Amount (0.04 m3)	Actual Mix Amount (1 m3)
Cement type I (OPC)	Kg	16.400		16.400	410.00
Water quantity	LTR	6.000		6.474	150.00
10mm Coarse Agg.	Kg	8.600	-2.00	8.428	215.00
20mm Coarse Agg.	Kg	13.000	-1.80	12.766	325.00
Expanded Perlite	Kg	2.600	-15.00	1.700	50.00
Sand (Fine Agg.)	Kg	29.000	0.80	29.232	725.00

4 RESULTS AND DISCUSSION

4.1 Hardened Concrete Tests Results

1. Density of Hardened Concrete

Reduction in density of hardened concrete is increase with the increasing of LWA replacement percentage, where it is increase gradually, lower density of EP was in P100 of 1426.34 kg/m^3 and for Cicolite C100 of 1911.33 kg/m^3 less than control mix density by 42.5% and 22.9% respectively as shown in Table 6.

Table 6: Density of hardened concrete for all percentages at age of 28 days.

Trial Mix No.	Density (kg/m^3)	Density Reduction (%)	Trial Mix No.	Density (kg/m^3)	Density Reduction (%)
N	2479.17	0.0	N	2479.17	0.0
C50	2152.72	13.2	P50	2094.98	15.5
C60	2089.51	15.7	P60	1996.06	19.5
C70	2042.40	17.6	P70	1914.89	22.8
C80	1974.36	20.4	P80	1782.96	28.1
C90	1953.03	21.2	P90	1621.94	34.6
C100	1911.33	22.9	P100	1426.34	42.5

2. Compressive Strength Results

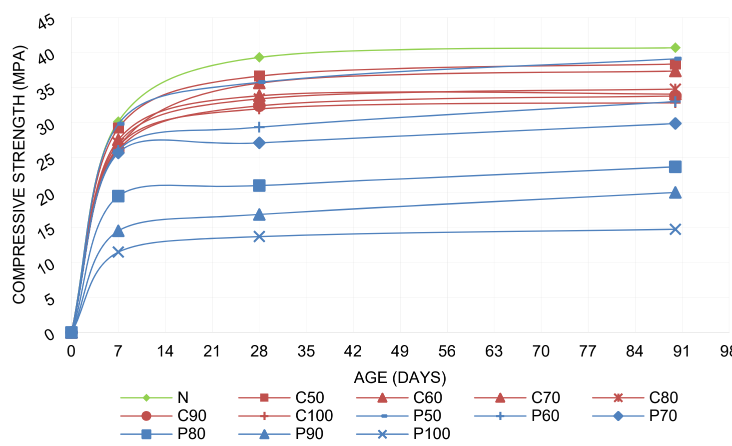

Figure 8: Improvement of compressive strength for all specimens during age compared with control mix.

Note the development of compressive strength of all specimens during age have gradual drop in strength with the increasing of LWA replacement percentage especially in EP at percentages more than 60%. The lowest strength got at 28 days is 13.7 MPa for P100 and 31.95 MPa for C100 less than control mix compressive strength by 65.1% and 18.8% respectively. As shown in next table.

Table 7: The reduction in strength comparing with control mix for all replacement percentages at 28 days.

Trial Mix No.	Ave. Strength (MPa)	Ach. % of 28 (MPa)	Strength Reduction (%)	Trial Mix No.	Ave. Strength (MPa)	Ach. % of 28 (MPa)	Strength Reduction (%)
N	39.32	40.42	0.0	N	39.32	40.42	0.0
C50	36.64	30.87	6.8	P50	35.76	27.71	9.1
C60	35.64	27.30	9.4	P60	29.32	4.73	25.4
C70	33.83	20.83	14.0	P70	27.09	-3.25	31.1
C80	33.38	19.23	15.1	P80	20.98	-25.08	46.7
C90	32.39	15.69	17.6	P90	16.85	-39.81	57.1
C100	31.95	14.10	18.8	P100	13.71	-51.05	65.1

3. Tensile Test Result

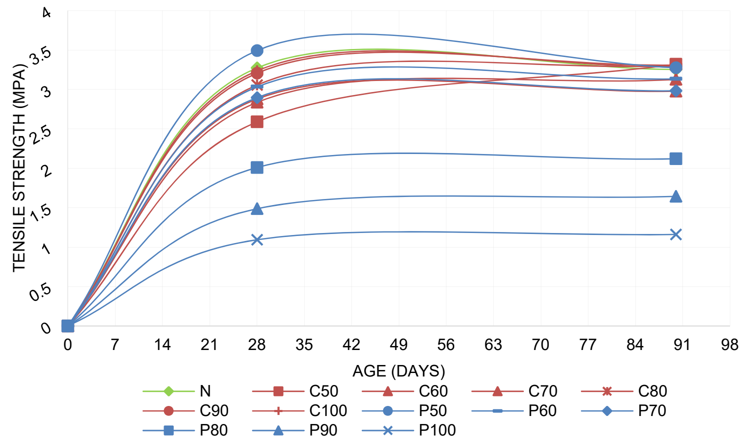

Figure 9: Improvement of tensile strength for all specimens during age compared with control mix.

The increasing of replacement percentage for Cicolite increase the tensile strength, While the exact opposite with EP. Where it recorded the highest value of tensile strength in P50 at 28 days equal 3.49 MPa. More than the control mix by 6.8% abnormal ratio for the rest can unreliable, also it raises questions about the study of the effect of using less ratios. The lowest got in P100 at 28 days equal 1.09 MPa less than control mix tensile strength by 66.6%. And 2.59 MPa for C50 less than control mix compressive strength by 20.8% as shown in next table.

Table 8: Tensile strength of all percentages at age of 28 days and compared with control mix.

Trial Mix No.	Ave. Strength (MPa)	Strength Reduction (%)	Trial Mix No.	Ave. Strength (MPa)	Strength Reduction (%)
N	3.27	0.0	N	3.27	0.0
C50	2.59	20.8	P50	3.49	-6.8
C60	2.88	12.0	P60	3.03	7.2
C70	2.84	13.3	P70	2.90	11.4
C80	3.06	6.5	P80	2.01	38.5
C90	3.21	1.9	P90	1.49	54.5
C100	3.24	1.0	P100	1.09	66.6

4. Beams Deformation

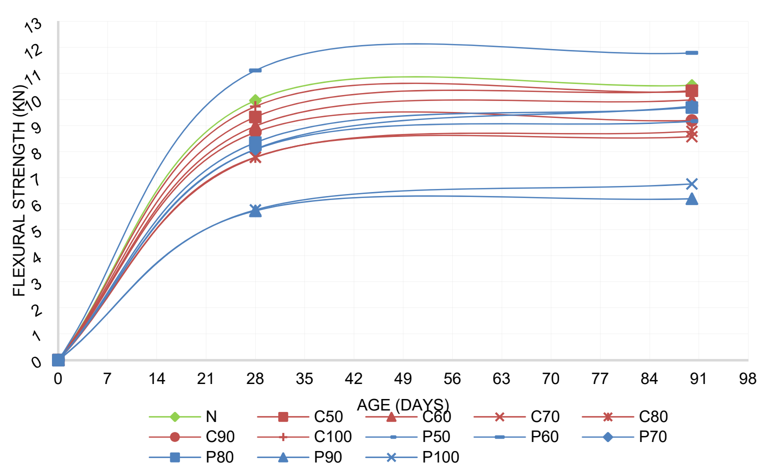

Figure 10: Improvement of flexural strength for all specimens during age compared with control mix.

The increasing of replacement percentage for Cicolite reduce the deformation, while for EP it is the opposite. All percentages show the increasing in deformation at 90 days more than 28 days except P100, P90, P80 and P70 where sharp decline occurred and significant increase in P05 from 28 days of 0.78 mm to 90 days of 7.07 mm. The highest value of deformation got in P100 at 28 days equal 16.39 mm then P90 of 9.95 mm and P80 of 7.34 mm, while P100 more than the control mix by 99.3%, and the lowest deflection got in control mix at 28 days equal 0.12 mm. These are unrealistic results for EP due to the excessive bleeding was happened in EP mixes.

5 CONCLUSION

The results indicate observations and conclusion as listed in following:

1. Slump (workability) increase with the increment of LWA replacement percentage, where it is higher in EP more than Cicolite and normal coarse aggregate. And slump is in direct proportionality with air content.
2. Fresh concrete density reduces with the increment of LWA replacement percentage, where it is higher in EP more than Cicolite.
3. Air content increase with the increment of LWA replacement percentage, where it is higher in EP more than Cicolite, reach up to 11.5% in 100% of EP replacement.
4. Density of hardened concrete reduced about quarter in 100% of Cicolite replacement and for half in 100% of EP replacement, with reduction of compressive strength of 18.8% for 100% of Cicolite replacement and more than the half for 100% of EP replacement of 65.1%. According to that Cicolite loss it is strength and density lower than EP wherever the LWA replacement percentage increase.
5. In Cicolite tensile strength increase with the increment of LWA replacement percentage to be almost equal the control mix strength of 3.27 MPa at 100% of Cicolite replacement, where it is totally opposite in EP this refer to the excessive bleeding was happened in EP mixes.

Figure 11: Some samples after splitting test.

From pervious photos we could note the segregation of course aggregate in EP samples especially in high percentages (see P80), this due to the aggregate weights different and excessive bleeding happened during casting stage.

6. Flexural strength showed different outcomes for both materials at 28 days and 90 days, but it is in Cicolite better than EP and both of them are lower than the normal course aggregate. And this refer to the segregation of materials was happened in EP mixes specially 80%, 90% and 100% of EP replacement.
7. Deformation of beams increased is acceptable ratio in Cicolite and in EP was not acceptable due to the segregation and separation of materials was happened in EP mixes specially 70%, 80%, 90% and 100% of EP replacement.

Best replacement percentage is 50% of Cicolite replacement for structural aspects (such as slabs, columns, and beams). It has achievement percentage of design strength at 28 days 31% with density of 2150 kg/m^3. The reduction in density compared to normal coarse aggregate is 13.2%. 100% of EP replacement has density of 1400 kg/m^3 lower than normal mix by 43% with compressive strength of 13.7 MPa used for nonstructural aspects (such as non-load bearing wall walls, and building envelop) to reduce dead load and take advantage of thermal properties.

References

Andaleeb, Saad Mohammad. 2005. “Concrete Mix Design for Lightweight Aggregates and an Overview on High Strength Concrete.” Department of Civil Engineering, Bangladesh University of Engineering & Technology,Bangladesh.

Anwar Hossain, Khandaker M. 2004. “Properties of Volcanic Pumice Based Cement and Lightweight Concrete.” *Cement and Concrete Research* 34 (2):283–91. https://doi.org/10.1016/j.cemconres.2003.08.004.

Chia, Kok Seng, and Min Hong Zhang. 2002. “Water Permeability and Chloride Penetrability of High-Strength Lightweight Aggregate Concrete.” *Cement and Concrete Research* 32 (4):639–45. https://doi.org/10.1016/S0008-8846(01)00738-4.

Dawood, E.T., and M. Ramli. 2008. “Rational Mix Design of Lightweight Concrete for Optimum Strength.” *@nd International Conference on Built Environment in Developing Countries (ICBEDC)*, no. Icbedc:515–26.

Demirboğa, Ramazan, Ibrahim Örüng, and Rüstem Gül. 2001. “Effects of Expanded Perlite Aggregate and Mineral Admixtures on the Compressive Strength of Low-Density Concretes.” *Cement and Concrete Research* 31 (11):1627–32. https://doi.org/10.1016/S0008-8846(01)00615-9.

Haque, M.N, H Al-Khaiat, and O Kayali. 2004. “Strength and Durability of Lightweight Concrete.” *Cement and Concrete Composites* 26 (4):307–14. https://doi.org/10.1016/S0958-9465(02)00141-5.

Mehta, P.K. 1987. *Natural Pozzolans: Supplementary Cementing Materials in Concrete*. CANMET Special Publication,1987. https://en.wikipedia.org/wiki/Pozzolan.

Mesut Aşik. 2006. “Structural Lightweight Concrete With Natural Perlite Aggregate and Perlite Powder,” no. September.

Mouli, M., and H. Khelafi. 2008. “Performance Characteristics of Lightweight Aggregate Concrete Containing Natural Pozzolan.” *Building and Environment* 43 (1):31–36. https://doi.org/10.1016/j.buildenv.2006.11.038.

Neville, A. M. 2010. *Concrete Technology*. 2nded. Pearson Education Limited.

NRMCA. 2016. “Concrete in Practice,CIP36-Structural Lightweight Concrete.” NATIONAL READY MIXED CONCRETE ASSOCIATION. 2016. http://www.nrmca.org/aboutconcrete/cips/36p.pdf.

Pallister, John S, Wendy A Mccausland, Sigurjón Jónsson, Zhong Lu, Hani M Zahran, Salah El Hadidy, Abdallah Aburukbah, et al. 2010. “Recorded by Dyke Intrusion in Saudi Arabia.” *Nature Geoscience* 3 (10). Nature Publishing Group:705–12. https://doi.org/10.1038/ngeo966.

Rossignolo, J A, M V C Agnesini, and J A Morais. 2003. “Properties of High-Performance LWAC for Precast Structures with Brazilian Lightweight Aggregates.” *Cement & Concrete Composites* 25 (1):77–82. https://doi.org/10.1016/s0958-9465(01)00046-4.

Satish, C., and L. Berntsson. 2003. *Lightweight Aggregate Concrete Science, Technology and Applications*. 1sted. New York: Noyes Publications.

SGS. 2016. “The Saudi Geological Survey (SGS).” 2016. 2016. http://www.sgs.org.sa/Arabic/studies/Pages/harat.aspx.

Topçu, Ilker Bekir, and Burak Işikdağ. 2008. “Effect of Expanded Perlite Aggregate on the Properties of Lightweight Concrete.” *Journal of Materials Processing Technology* 204 (1–3):34–38. https://doi.org/10.1016/j.jmatprotec.2007.10.052.

Türkmen, Ibrahim, Ramazan Demirboğa, and Rüstern Gül. 2006. “The Effects of Different Cement Dosages, Slumps and Pumice Aggregate Ratios on the Thermal Conductivity and Density of

Concrete." *Computers and Concrete* 3 (2–3):163–75. https://doi.org/10.1016/j.cemconres.2003.09.018.

Yasar, Ergul, Cengiz Duran Atis, Alaettin Kilic, and Hasan Gulsen. 2003. "Strength Properties of Lightweight Concrete Made with Basaltic Pumice and Fly Ash." *Materials Letters* 57 (15):2267–70. https://doi.org/10.1016/S0167-577X(03)00146-0.