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Mechanical Properties of Pumice Lightweight Aggregate Concrete Compared to Normal Concrete

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ABSTRACT

Structural lightweight concrete is "significant in contemporary construction. This concrete provides technical and environmental benefits, so it is intended for use in the next millennium. Density is frequently more important than strength for lightweight concrete structural applications. A lower density at the same strength level reduces “self-weight”, "foundation size," and construction expenses. In addition, using lightweight concrete as opposed to standard weight concrete could provide additional benefits such as heat and sound insulation. A special type of "self-cured lightweight concrete" has been developed to utilize the voids in lightweight aggregate's water reservoirs for curing. The experimental investigation of the structural behavior of lightweight concrete as a function of concrete type and bonding was conducted. Cubes and cylinders were employed in the experimental investigation. Concrete type (normal weight concrete and lightweight concrete) and cement content (350, 400, and 450 kg/m3) were considered as test variables.

Keywords: Lightweight Concrete; Lightweight Aggregate; Pumice; Mechanical Properties; and Concrete Bond.

1 INTRODUCTION

Occasionally, the requirement to reduce the weight of a structural element is equally as critical as the need to increase its strength, especially in massive structures such as tall buildings and bridges, where the weight of the structure itself is one of the key issues designers face. For concrete structures, obtaining monolithic fair-faced concrete with high aesthetic attributes is a vital necessity. Presently, Lightweight Aggregates (LWA) are accessible in a wide variety of densities, strengths, and sizes. This makes it possible to design extremely diverse Lightweight Concrete (LWC) structures. including a lightweight concrete with high strength for structural applications and a lightweight concrete with a very low density for insulation. This type of concrete contains voids that reduce its own weight [1]. Lightweight concrete (LWC) has a dry density between 300 to 1840 kg/m^3 and weighs less than standard weight concrete (NWC). depending on the materials employed. In the second century, it was first employed in the construction of "The Pantheon" [2]. Common uses for lightweight concrete include high-rise building slabs and joists, bridge decks of highway bridges, and offshore and marine structures [3 to 5]. In lieu of aggregates of standard weight, a lightweight aggregate with a low apparent specific gravity is utilised [6]. Natural aggregates are comprised of scoria, tuff, pumice, diatomite, and volcanic cinders; with the exception of diatomite, these types are all of volcanic origin. In addition, the classification [7] includes artificial lightweight aggregates Examples include expanded clay, shale, slate, diatomaceous shale, vermiculite, obsidian, and perlite. All or a portion of the aggregate in lightweight aggregate concrete is composed of porous particles with a lower density than natural normal weight aggregate [8]. Fine and coarse aggregates of varying sizes are embedded within a cement paste to form lightweight concrete. It may contain air that was intentionally entrained using air-entraining additives. Use of chemical admixtures and/or finely divided mineral admixtures in the production of concrete to improve or alter its qualities or to obtain a more cost-effective concrete [9]. lightweight aggregate concrete requires less compaction. Long vibration durations for lightweight aggregate concrete do not result in a cement paste or mortar surface concentration. In contrast, coarse aggregate particles tend to rise and may leave the concrete to produce a layer of light, loose aggregate. Consequently, it might result in low homogeneity and loss of stability in fresh concrete [10, 11]. It is possible to produce structural lightweight concrete mixtures with equal strength to conventional weight structural concrete. Therefore, lightweight structural concrete delivers structural parts with a more efficient strength-to-weight ratio. Additionally, compared to NWC, LWC has significantly superior fire resistance and significantly reduced heat transmission. In addition, although the cost of Despite the fact that the cost of structural lightweight concrete is somewhat greater than that of regular weight concrete, the reduction in concrete volume results in a lower total cost [12]. The primary advantages of using lightweight concrete in the construction and rehabilitation of bridges [13] are increased width or number of traffic lanes, increased load capacity, balanced cantilever construction, reduction in seismic inertial forces, increased cover with equal weight, thicker slabs, improved deck geometry with thicker slabs, and longer spans that reduce pier costs. Natural lightweight aggregates such as pumice and scoria may be used to produce concrete weighing between 800 and 950 kilogrammes per cubic metre (kg/m3), and up to 1,800 kg/m3 [14]. The rapid cooling of molten volcanic material caused by the release of gases during lava solidification [14] produces pumice stone, a naturally occurring, lightweight aggregate. As a structural material, the benefits of lightweight aggregate concrete were recognised as early as Roman times. According to the research of numerous authors [15], Due to the air gaps in lightweight aggregate, lightweight concrete has the apparent benefits of a high strength-to-weight ratio, good tensile strength, a low thermal expansion coefficient, and improved heat and sound insulation properties.

2 EXPERIMENTAL PROGRAM

2.1 General Properties

The experimental work conducted in this project investigated the behavior of lightweight concrete. The parameters studied in these tests were the concrete strength, unit weight, Modulus of elasticity, and concrete bond.

2.2 Material Properties

The materials used were ordinary Portland cement, natural sand, crushed stone (dolomite), coarse lightweight aggregate, silica fume, super-plasticizers, and tap drinking water. The evaluation of used materials was conducted in accordance with Egyptian standard specifications. In the sections that follow, the properties of the employed materials are displayed and discussed.

2.2.1 Ordinary Portland cement

The cement utilized was standard Portland cement CEM I 42.5 N from Tourah cement company. It was tested according to ESS 4756-1/2013 [16]. The physical and mechanical characteristics of cement, in addition to its chemical composition are given in Table 1.

Table 1. The physical and mechanical characteristics of cement

Property		Result	Limits*
Compressive strength (MPa)	2 days	21.88	Not less than 10
	28 days	43.33	Not less than 42.5
Soundness (Le Chatelier) (mm)		1	Not more than 10
Specific surface area (cm2/gm.)		3120	>2250
Setting time (min.)	Initial	135	Not less than 60
	Final	180	——

* ESS 4756-1/2013 [16]

2.2.2 *Normal Weight Aggregate*

2.2.2.1 *Fine aggregate*

The used fine aggregate was local natural sand composed mainly of siliceous materials. The used sand was tested according to the Egyptian Guide for Laboratory Tests for concrete materials issued 2007 [17]. The characteristics of sand are given in table 2 and grading is given in table 3 and figure 1.

Table 2. The characteristics of the used sand

Property	Result	Limits*
Bulk density (t/m^3)	1.72	——
Specific gravity	2.63	——
Clay and fine materials (%)	0.58	≤ 4%
Chlorides (%)	0.037	Not more than 0.06
Sulphates (%)	0.061	Not more than 0.4

***** ECOP 203/2007 [17]

Table 3. Sieve analysis for sand

Sieve opening (mm)		10	5	2.63	1.18	0.6	0.3	0.15
Passing (%)		100	98.8	93.8	81	53.8	13.6	2.2
Limits *	Max.	100	100	100	100	100	70	15
	Min.	100	89	60	30	15	5	0

***** ECOP 203/2007 [17]

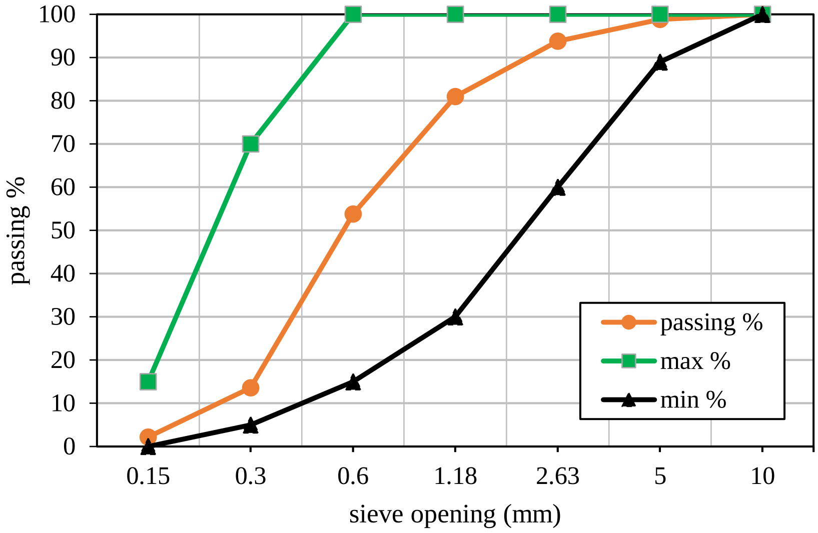

Fig. 1. Grading curve of sand

2.2.2.2 Coarse aggregate

The used coarse aggregate was crushed dolomite with a nominal maximum size of 14 mm. It was free from impurities and organic matters. The used crushed dolomite was tested according to the Egyptian Guide for Laboratory Tests for concrete materials issued 2007 [17]. The grading is given in table 4 and fig. 2, and characteristics of crushed dolomite are given in table 5.

Table 4. Sieve analysis for crushed dolomite

Sieve opening (mm)		37.5	20	14	10	5	2.36
Passing (%)		100	100	95.4	67.8	6.26	0
Limits *	Max.	100	100	100	85	10	0
	Min.	100	100	90	50	0	0

* ECOP 203/2007 [17]

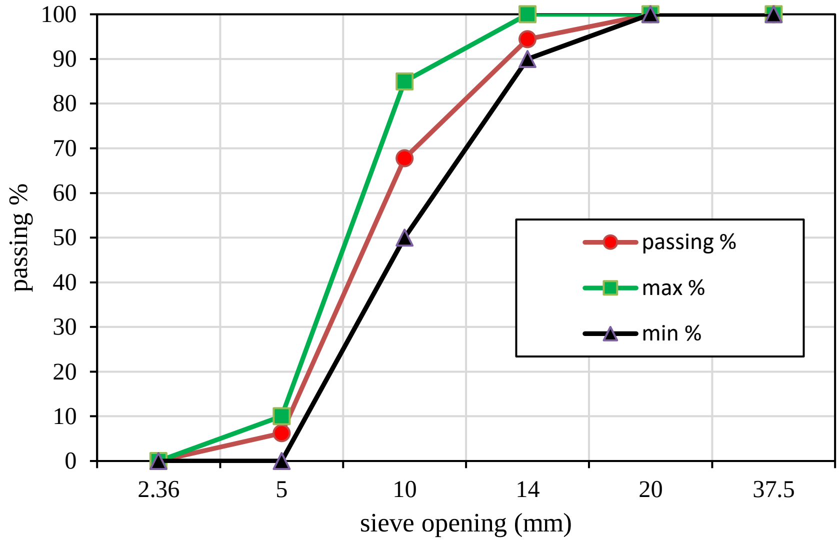

Fig. 2. Grading curve for crushed dolomite

Table 5. Characteristics of the used crushed dolomite

Property	Result	Limits*
Bulk density (t/m3)	1.52	——
Specific gravity	2.54	——
Water absorption (%)	2.11	Not more than 2.5
Flakiness index (%)	15.8	Not more than 25
Elongation index (%)	17.6	Not more than 25
Impact value (%)	11.1	Not more than 45
Crushing value (%)	20.5	Not more than 30
Clay and fine materials (% by weight)	0.43	Not more than 4
Los angles abrasion loss (%)	22.3	Not more than 30
Chlorides (%)	0.015	Not more than 0.04
Sulphates (%)	0.032	Not more than 0.4

* ECOP 203/2007 [17]

2.2.3 Coarse lightweight aggregate

The used coarse lightweight aggregate (LWA) was natural pumice aggregate shown in fig. 3. Pumice passing from 14 mm sieve and retained on 4.75 mm sieve. Testing of coarse lightweight aggregate was carried out according to the Egyptian Guide for Laboratory Tests for Concrete Materials issued 2007 [17] and ASTM [18]. Table 6 shows the chlorides and Sulphates content before and after soaking.

Characteristics of LWA: Bulk density 500kg/m^3, specific gravity 0.835, water absorption 14%, flakiness index 21.8%, elongation index 11.7%, impact value 30% and los angles abrasion loss 50.8%.

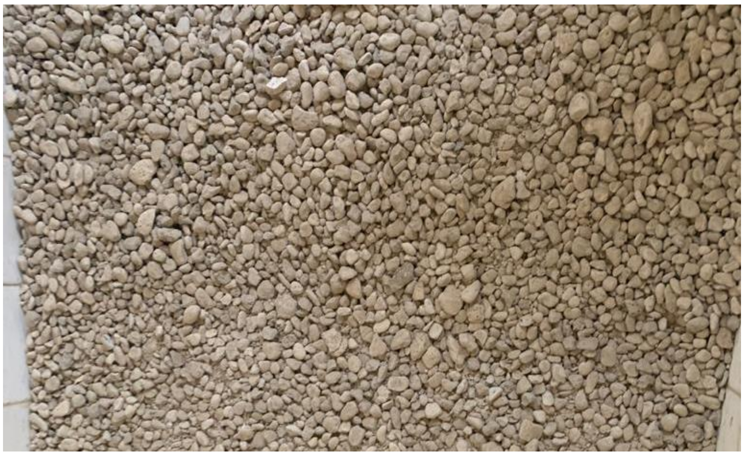

Fig. 3. Natural Pumice

Table 6. Chlorides and Sulphates content in LWA

Property	Result		Limits*
	Before-soaking	After-soaking	
Chlorides (%)	0.674	0.005	Not more than 0.04
Sulphates (%)	0.189	0.014	Not more than 0.4

* ECP 203/2007 [17]

The grading of coarse lightweight aggregate is given in fig. 4, and table 7 comparing it to maximum and minimum limits according to ASTM C330-4 [18].

Table 7. Sieve analysis for LWA

Sieve opening (mm)		25	19	14	9.5	4.75	2.63	1.18
Passing (%)		100	99.8	96.4	70.2	3.55	0.15	0
Limits*	Max.	100	100	100	80	20	10	0
*ASTM C330-4 [18]	Min.	100	100	90	40	0	0	0

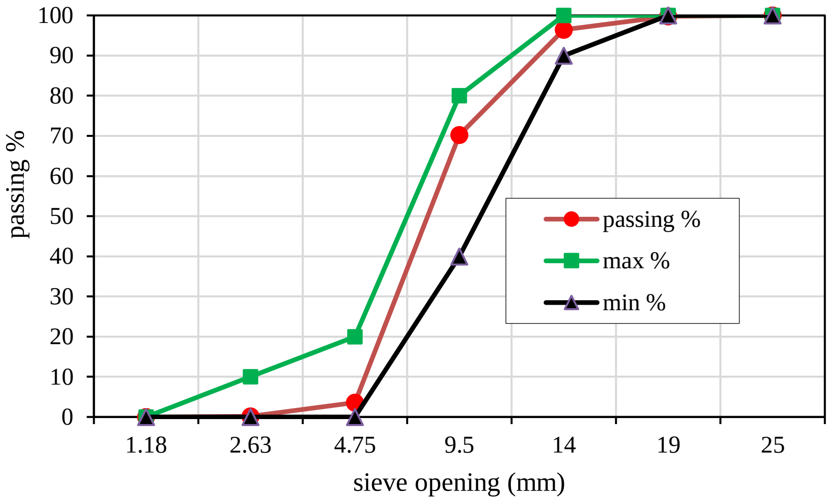

Fig. 4. Grading curve of lightweight aggregate

2.2.4 Admixtures

A commercial silica fume used as a mineral admixture and was purchased locally from Metallurgical & Construction Chemicals in Egypt. Silica fume is a byproduct of the manufacturing of silicon and ferrosilicon alloys. Physical characteristics and chemical composition of silica fume: light grey colour, specific gravity of 2.15, and bulk density between 260 and 320 kg/m3.

Super-plasticizer material that used to improve the workability of concrete is "Sikament-NN" from Sika Egypt Company.

Table (8): Technical data of Sikament-NN

Property	Description
Base	Naphthalene formaldehyde sulphonate
Form	Liquid
Color	Brown
Odor	None
Density (at 20 °C)	1.200 kg/l
pH Value	Not more than 8
Dosage	0.6 – 3 % by weight of cement

2.3 Concrete Mixtures

Two series of concrete mixes were cast. The first series was normal weight concrete (NWC) mixes, while the second series was self-cured lightweight concrete (SCLWC) mixes. Each series included four mixes with 350 kg/m3 cement content, 400 kg/m3 cement content, 450 kg/m3 cement content and

450 kg/m3 cement content plus 10 % silica fume (as a mineral additive). The ratio of fine aggregate was 45% of the total aggregate content in NWC mixes. In SCLWC mixes, coarse lightweight aggregate was used to replace 75 % by volume of crushed dolomite. Constant water content of 140 l/m3 of concrete was used in all mixes. Hence, variable dosage of super plasticizer was used to maintain the target slump of 100 ± 20 mm. It should be noted that coarse aggregates were used in a saturated surface dry condition during mixing while fine aggregates were used as received.

Note that after casting all specimens, they were moulded and immersed in a water-saturated curing tank at 25 degrees Celsius until they reached the testing age. Fig. 5a depicts the preparation of specimens for the pull-out test, which was conducted at the age of 365 days. Fig. 5b depicts a portion of standard cubes and cylinders after curing.

Fig. 5a. Compaction on concrete cubes and curing

Fig. 5b. Compaction on concrete cubes and curing

Table 8. The proportions of concrete mixes.

Concrete Type	Cement Kg/m^3	NWA Coarse Kg/m^3	NWA Fine Kg/m^3	LWA (pumice) Kg/m^3	Water Kg/m^3	Silica Fume Kg/m^3	Super-Plasticizer Kg/m^3
C	350	1053	862	-	140	-	8
	400	1031	843		140		8
	450	1008	825		140		8
	450	976	799	-	140	45	10
LWC	350	263	862	260	140	-	8
	400	258	843	254	140		8
	450	252	825	249	140		8
	450	244	799	241	140	45	10

2.4 TESTING PROCEDURES

Tests were conducted on fresh concrete to check its workability. In addition, hardened concrete cubes.

2.4.1 Testing of fresh concrete properties

2.4.1.1 Slump test

Slump test was carried out on fresh concrete just after mixing to check the workability of concrete. The test was conducted in accordance with the Egyptian standard specifications ESS 1658/2008 [19]. Fig. 6, shows the slump test.

Fig. 6. Slump test

2.4.2 Testing of hardened concrete properties

2.4.2.1 Compression test

Compressive strength is the maximum measured resistance to axial loading of a concrete specimen. The experiment was conducted after 7 and 28 days. During testing, a 15 x 15 x 15 cm specimen was positioned centrally in the compression testing machine, and load was applied continuously and uniformly perpendicular to the tamping direction. The maximum load was recorded after the load was increased until failure. Figure 7 depicts the test. The calculation for compressive strength was as follows: Strength under compression = (P / A)

Fig. 7. Compression test

2.4.2.2 Pull-0ut test

At 365 days, determine the bond strength between concrete and embedded steel and fibre rebars. The selected specimens were concrete cylinders (150 mm x 300 mm) with embedded rebar of full height and a 400 mm free end for testing purposes.

3 RESULTS AND DISCUSSIONS

This study investigates the behavior of self–cured lightweight concrete compared with that of normal weight concrete. An experimental program included the investigation of the behavior of concrete cubes. Type of concrete and cement content the main variables.

3.1 **Effect of concrete type**

Fig. 8, show the effect of concrete type on the compressive strength of NWC and LWC mixes, respectively. It can be observed that the compressive strength of LWC is lower than that of NWC. The compressive strength of concrete decreased by 42.8%, 41.9% and 39.9% for concrete mixes with 350, 400, 450 kg/m3 cement content, respectively and decreased by 40.7% for concrete mix 450 kg/m3 cement content plus 10% silica fume, by changing concrete type from NWC to SCLWC.

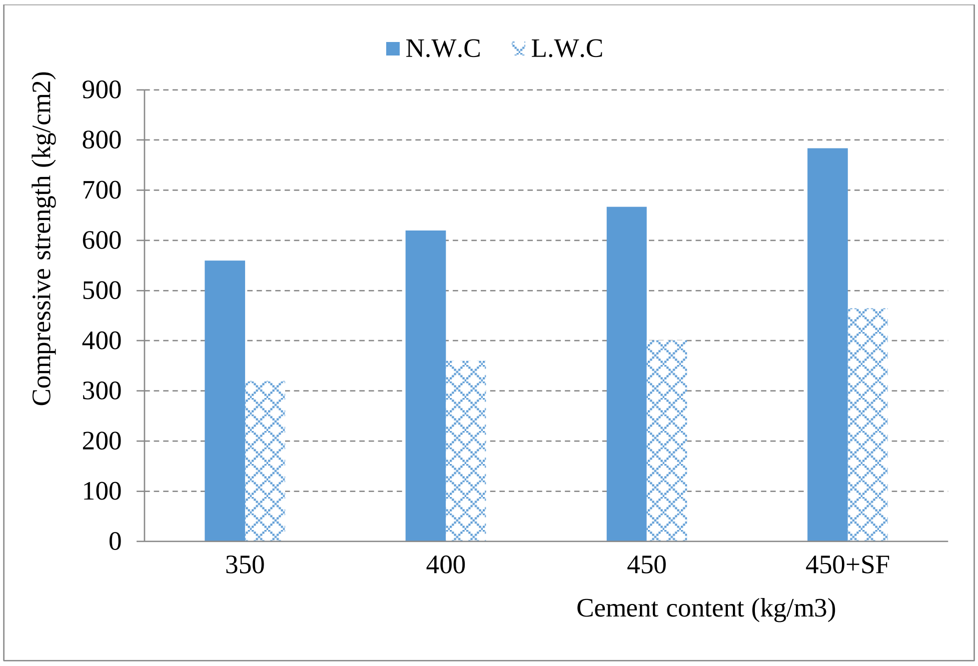

Fig.8. Effect of concrete type on the compressive strength of concrete cubes (350 kg/m^3, 400 kg/m^3 and 450 kg/m^3 cement content).

Fig. 9, show the effect of concrete type on the unit weight of NWC and SCLWC mixes, respectively. It can be observed that the unit weight of SCLWC is lower than that of NWC. The unit weight of concrete decreased by 19.9%, 18.8% and 18.6% for concrete mixes with 350, 400, 450 kg/m3 cement content, respectively and decreased by 17.4% for concrete mix 450 kg/m3 cement content plus 10% silica fume, by changing concrete type from NWC to SCLWC.

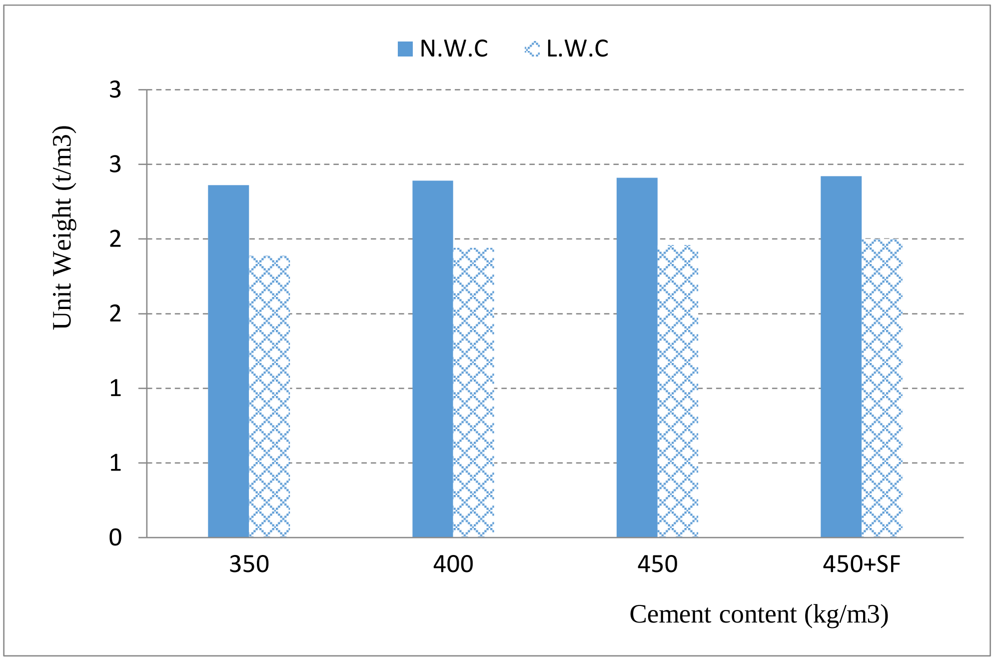

Fig. 9. Effect of concrete type on the unit weight of concrete cubes (350 kg/m^3, 400 kg/m^3 and 450 kg/m^3 cement content.

3.2 Effect of cement content and silica fume percentage

The effects of cement content and silica fume percentage on the compressive strength of NWC and SCLWC mixtures are depicted in Figures 10 and 11, respectively. Increasing the cement content of concrete increased its compressive strength. The compressive strength of NWC increased by 12.3% when the cement content was increased from 350 to 400 kg/m3 and by 20.6% when the cement content was increased from 350 to 450 kg/m3, whereas the compressive strength of LWC increased by 11.7% when the cement content was increased from 350 to 400 kg/m3 and by 23% when the cement content was increased from 350 to 450 kg/m3.

With the addition of silica fume to cement, the compressive strength of concrete was enhanced. In average, the compressive strength of NWC and LWC increased by 16.1% and 14.6% respectively by using 10% silica fume.

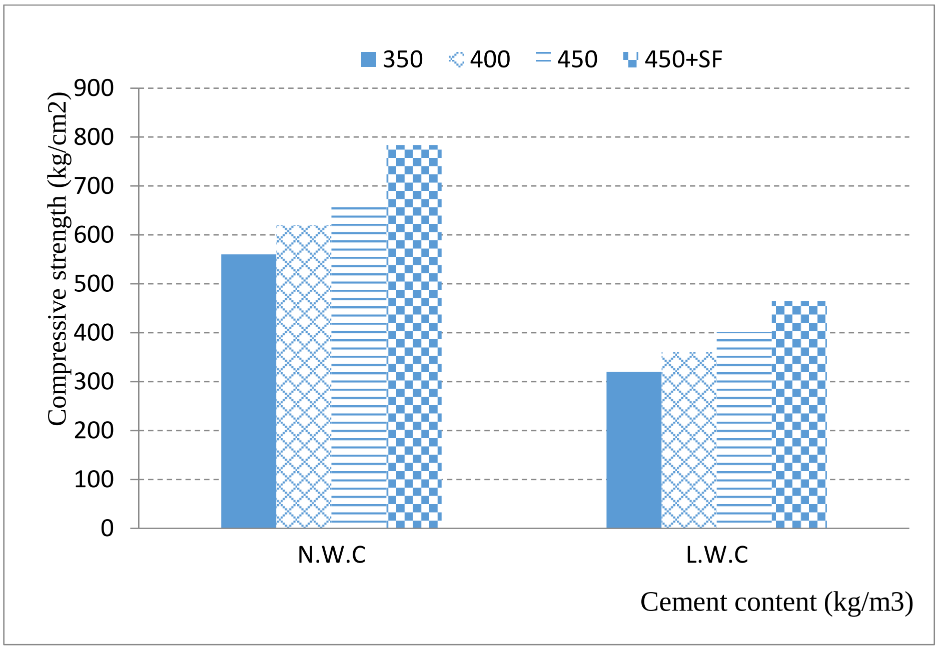

Fig. 10. Effect of cement content and silica fume on compressive strength of concrete cubes (350 kg/m^3, 400 kg/m^3 and 450 kg/m^3 cement content.

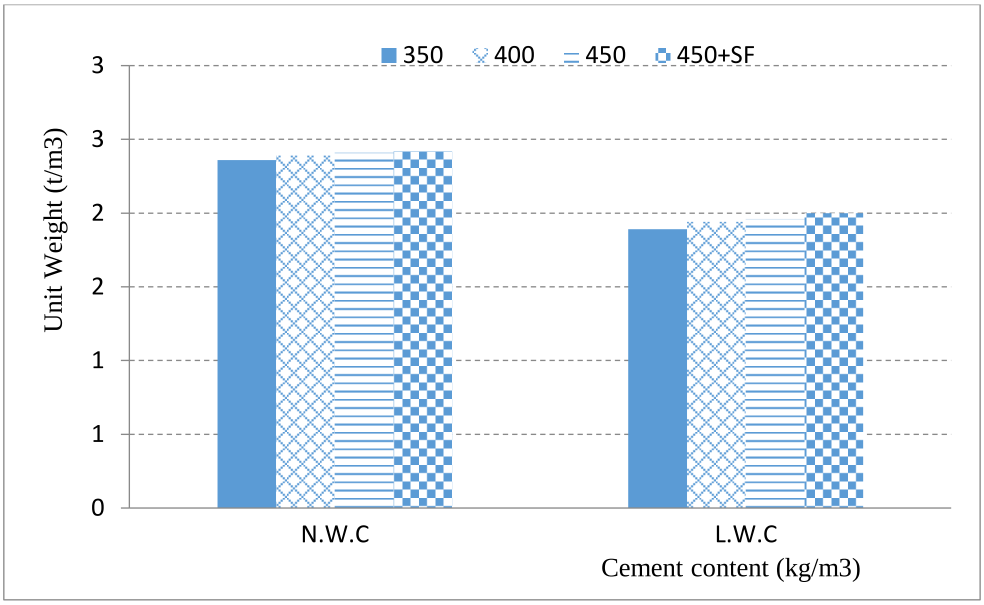

Fig. 11. Effect of cement content and silica fume on the unit weight of concrete cubes (350 kg/m^3, 400 kg/m^3 and 450 kg/m^3 cement content.

3.3 Pull-out test results

The pull-out test was conducted on concrete cylinders after 365 days for all NWC and LWC concrete mixtures with bar diameter 12 mm and embedded length 30 cm. NWC at compressive strength 620 and 670 kg/cm^2 have bond strength 6.93 and 7.25 kg/cm^2 also for LWC at compressive strength 360 and 420 kg/cm^2 have bond strength 6.34 and 7.20 kg/cm^2. It was discovered that reinforcing LWC with steel bars resulted in 6.75% less bond strength than reinforcing NWC with steel bars. The results indicate that the bond strength of LWC is marginally less than that of NWC.

4 SUMMARY AND CONCLUSIONS

4.1 Summary

In this investigation, the behaviour of lightweight concrete was investigated experimentally. Experiments were conducted to determine the impact of concrete type, cement content, and silica fume addition on compressive strength and unit weight.

4.2 Conclusion

Based on the presented experimental the following conclusions can be presented:

1- 1- Increasing cement content increased the compressive strength of concrete. The compressive strength of concrete increased by 12.3% when the cement content was increased from 350 to 400 kg/m3 and by 20.6% when the cement content was increased from 350 to 450 kg/m3 for NWC, whereas for SCLWC the compressive strength increased by 11.7% when the cement content was increased from 350 to 400 kg/m3 and by 23.0% when the cement content was increased from 350 to 450 kg/m3.

2- Increasing cement content increased the unit weight of concrete. The unit weight of concrete increased by 1.35 % when the cement content was increased from 350 to 400 kg/m3 and by 2.35 % when the cement content was increased from 350 to 450 kg/m3 for NWC. For SCLWC, the unit weight increased by 1.45 % when the cement content was increased from 350 to 400 kg/m3 and by 3.3% when the cement content was increased from 350 to 450 kg/m3.

3- The compressive strength of concrete increased by using silica fume as an addition. In average, the compressive strength of silica fume concrete of NWC and SCLWC increased by 16.1% and 14.6% respectively by using 10% of silica fume as an addition.

4- The unit weight of concrete increased by using silica fume as an addition. In average, the unit weight of silica fume concrete of NWC and SCLWC increased by 0.8% and 1.6% respectively by using 10% of silica fume as an addition.

5- The compressive strength of concrete decreased by using 75% of coarse lightweight aggregate. The compressive strength of concrete decreased by 42.8%, 41.9% and 39.9% for concrete mixes 350, 400, 450 kg/m3 cement content and decreased by 40.7% for concrete mix 450 kg/m3 cement content with 10% silica fume, respectively.

6- The unit weight of concrete decreased by using 75% of coarse lightweight aggregate. The unit weight of concrete decreased by 19.9%, 18.8% and 18.6% for concrete mixes 350, 400, 450 kg/m3 cement content and decreased by 17.4% for concrete mix 450 kg/m3 cement content with 10% silica fume, respectively by replacement percentage of normal weight aggregates by lightweight aggregates.

7- The bond strength of LWC is less than the bond strength of NWC with steel bars by 6.75%.

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