Al-Azhar University Civil Engineering Research Magazine (CERM)
Vol. (44) No. (3) october . 2022

SOME MECHANICAL PROPERTIES OF STRUCTURAL LIGHTWEIGHT CONCRETE PRODUCED WITH DIFFERENT TECHNIQUE

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ملخص البحث :

تعتبر الخرسانة الإنشائية خفيفة الوزن مادة مهمة في البناء الحديث وقد زاد استخدامها على نطاق واسع في الهندسة المدنية كبديل مناسب للخرسانة ذات الوزن العادي، بغرض تقليل الحمل الميت للهيكل، مما يسمح للمصمم بتقليل أبعاد العناصر الإنشائية، وبالتالي تقليل كمية حديد التسليح، الأمر الذي ينعكس على تقليل تكاليف الهيكل بأكمله، بالإضافة إلى مزايا أخرى مثل عزل الصوت والحرارة. خلال العمل التجريبي في هذه الدراسة، تم إنتاج نوعين من الخرسانة الإنشائية خفيفة الوزن: النوع الأول، إنتاج خرسانة إنشائية خفيفة الوزن باستخدام ركام الزيوليت المكلس (ساعتين، 550°c) كركام (خشن وناعم) وكعامل لتوليد الفقاعات، وبالتالي، يحتوي خليط الخرسانة على جزء تدريجي تصاعدي من الحجم بين الزيوليت الخشن والناعم {(60٪:40٪)، (50٪:50٪)، (40٪:60٪)، (20٪ :80٪) (خشن : ناعم)}، وأسمنت، وماء، وملدّن فائق. النوع الثاني، إنتاج خرسانة إنشائية خفيفة الوزن باستخدام الخفاف كركام خشن خفيف الوزن، وبالتالي، يحتوي خليط الخرسانة على استبدال تصاعدي للحجم بين ركام الخفاف والركام الخشن بالوزن الطبيعي {(50٪:50٪)،(65٪: 35٪)، (75٪:25٪)، (100٪:0٪)، (ركام خفاف:ركام خشن عادي)}، الأسمنت، الماء، وملدن فائق، لتحديد تأثير إضافة ركام الزيوليت والخفاف على خصائص الخرسانة خفيفة الوزن الطازجة والمتصلبة (التشغيلية، مقاومة الضغط، مقاومة الشد، مقاومة الأنحناء، مقاومة التماسك، معامل المرونة، الامتصاص)، بالإضافة إلى ذلك، كان التحقيق حول السلوك الأنشائي للكمرات الخرسانية خفيفة الوزن، وأجريت الدراسة التجريبية على ثلاثة كمرات خرسانية مسلحة، كمرة واحدة من خليط الزيوليت {(60٪:40٪) (خشن:ناعم)} وكمرة واحدة من خليط الخفاف {(65٪:35٪) (ركام خفاف:ركام خشن عادي)} بكثافات مماثلة وتمت مقارنتها مع سلوك الانحناء لكمرة خرسانة الوزن العادي. وأظهرت النتائج أن جميع النسب المدروسة لمخاليط الزيوليت والخفاف حققت مقاومة ضغط أعلى من 17 ميجا باسكال ووحدة وزن أقل من 2000 كجم / متر مكعب، وهذا يتوافق مع المعايير المحددة (ACI 213R-14) للخرسانة الإنشائية خفيفة الوزن، وكان سلوك الأنحناء لخرسانة الزيوليت وخرسانة الخفاف مشابهاً لخرسانة الوزن العادي.

الكلمات المفتاحية: الخفاف، الزيوليت، الخواص الميكانيكية، الخرسانة الانشائية خفيفة الوزن، سلوك الانحناء.

ABSTRACT:

Structural lightweight concrete (SLWC) is an important material in modern construction has increased its widespread use in the civil engineering, as a convenient alternative to normal weight concrete (NWC), for the purpose of reducing the dead load of the structure, allowing the designer to reduce the dimensions of the structural elements, and thus reduce the amount of reinforcing steel, which is reflected on reducing the costs of the entire structure, in addition, other advantages such as sound and heat insulation can be obtained. During the experimental work in this study, two types of structural lightweight concrete were produced: first type, structural lightweight concrete production using calcined zeolite aggregate (550c^{o} for 2h) as an aggregate (coarse & fine) and bubble generating agent, consequently, the concrete mixture contain an ascending gradual portion of volume between coarse and fine zeolite{ 60%:40% (C:F), 50%:50% (C:F), 40%:60% (C:F), and 20%:80% (C:F) }, cement, water, and superplasticizer. Second type, structural lightweight concrete production using pumice as a lightweight coarse aggregate, consequently, the concrete mixture contain an ascending replacing of volume between pumice aggregate and normal weight coarse aggregate (50%:50%, 65%:35%, 75%:25%, and 100%:0%, pumice aggregate: normal coarse aggregate), cement, water, and superplasticizer, to determine the effect adding of zeolite and pumice aggregates on the properties of fresh and hardened lightweight concrete (slump test, compressive strength, tensile strength, flexural strength, Pull-out strength, modulus of elasticity, sorptivity test), in addition, the investigation was about the structural behaviour of lightweight concrete beams, and the experimental study was conducted on three reinforced concrete beams, one beam of zeolite mixture (60%:40% (C:F)) and the other one of pumice mixture (65% pumice: 35% normal weight aggregate) of similar densities were compared with the flexural behavior of normal weight concrete beam. the results showed that all studied ratios of zeolite and pumice mixtures achieved compressive strength higher than 17Mpa and unit weight less than 2000kg/m^3, this is in accordance with the specific standards (ACI 213R-14) for structural lightweight concrete, the flexural behaviour of zeolite concrete and pumice concrete was similar to that of normal weight concrete.

Keywords: Pumice; Zeolite; Mechanical properties; Structural lightweight concrete; Flexural behaviour.

1 INTRODUCTION

The use of structural lightweight concrete (SLWC) dates back more than two thousand years, in the middle of the twentieth century it started to assume greater relevance in construction[1], Over the past few decades, the use of structural lightweight concrete increased widely in the civil engineering. In many cases, structural lightweight concrete (SLWC) may be treated as a convenient alternative to normal weight concrete (NWC). It is especially used in structures where a lower dead load, a longer span elements, and better thermal insulation are required. Therefore, structural lightweight concrete (SLWC) is applied for both precast and monolithic constructions, in particular, high rise and public buildings, sports and entertainment halls, stadiums, bridges and viaducts, car parks, oil rigs, tunnels, tanks, roads, and many other engineering structures[2,3]

Structural Lightweight concrete has a dry density ranging from 1120 kg/m^3 to 1920 kg/m^3 is 23–80% lighter in weight than normal weight concrete with cylinder compressive strength >17mpa after 28 days according to (ACI 213R)[4], Structural Lightweight concrete (SLWC) is made either by replacing all normal-weight aggregates (fine & coarse), or only the coarse fraction, with lightweight aggregates (LWA), which can be natural or artificial[5], natural such as pumice, zeolite, diatomite, and artificial such as foamed slag, expanded perlite, sintered fly ash[6,7], Pumice has many prospective properties such as low density, good thermal insulation, good fire resistance and non-combustibility, acceptable compressive strength, reasonable elasticity and porous structure with low permeability which qualify it for structural lightweight concrete manufacture [8,9], Pumice stone is a natural lightweight (sponge-like) aggregate shaped throughout the fast cooling and solidification of volcanic matter (molten lava) which is generally rhyolitic in conformation, The pumice porous structural is formed by bubbles formation or tricking millions of tiny air voids when gases in molten lava are tricked during cooling, Pumice colour is frequently gray or white or ranges from white to gold to brown to black. This mainly depends on the chemical composition of the pumice[8], Due to strict environmental guidelines to recycle waste, the use of pozzolanic materials for the creation of lightweight concrete, such as slags, natural zeolite, fly ash, and silica fume, has recently attracted attention[10]. Natural zeolites have been utilized for different purposes in assorted fields including wastewater treatment, gas sanitization, and development[11], Zeolites are crystalline alumina silicate having regular holes, channels, and cavities. they are a preferred material for extensive industrial applications because they have unique qualities including ion exchange, molecular sieves, a wide surface area, and catalytic activity[10]. Along with insulation and low density, the pumice and zeolite aggregates also offer structural qualities[12]. Some researchers studied the effect of using pumice and zeolite aggregates on the properties of concrete such as,. Kurt et al. [13] produced a lightweight concrete with a dry density of about 845–1031 and 1014–1037 kg/m3 containing 100% pumice aggregate. The pumice aggregate showed good properties and performance in the lightweight concrete. Karakurt et al. [14] investigated the utilization of natural zeolites as lightweight aggregates. They produced an autoclaved aerated concrete (AAC) using natural zeolites (clinoptilolite) at 25%, 50%, 75%, and 100% to replace silica sand. They found that the replacement of 50% of the cement with the natural zeolite is an optimum proportion overall in terms of compressive strength, lower unit weight, and higher thermal insulation capacity of the AAC. Otherwise, in the process of producing the AAC, a natural zeolite was calcined at 500 °C for 2 h to utilize it as a foaming agent. The pre-treatment of natural zeolite (i.e., calcination) provided the highest compressive strength, resulting from a high unit weight and low porosity of the AAC. Karthika, R,B et al [15]. They conducted a study on lightweight concrete by using pumice aggregate. Replacing pumice stone with coarse aggregate is said to be structural lightweight concrete solves to reduce the self-weight of building, The main objective is to determine whether pumice stone lightweight concrete can be used as structural concrete, to determine the compressive strength and split tensile strength of lightweight concrete having density below 1800kg/m3 and to study the effect of various types replacements (20%, 50%, 80%, 100%) of natural aggregate by lightweight aggregate (pumice) and conventional concrete on 7, 28 days, From the study, it is found that 50% replacement of pumice lightweight aggregate with conventional coarse aggregate is the optimum replacement level and the increasing percentage of pumice aggregate decreases the strength of concrete. Pumice is natural. It has more pores. Thus, it has high water absorption, and less density than the normal-weight aggregate (NWA). Therefore, the compressive strength and unit weight of LWC produced with pumice aggregate is expected to be less than the concrete produced with normal aggregate. The effect of pumice as coarse aggregate replacement was studied on the concrete properties. The use of PLA of 50% to 100% can be categorized as SLWC. Asmaa et al.[16] investigated the utilization of calcined zeolites as lightweight aggregates and bubble generation factor. They produced an lightweight concrete (LWC) using calcined zeolites (clinoptilolite), and the ratio was fine to coarse zeolite are (25%FZ,75%CZ), (50%FZ,50%CZ), (75%FZ,25%CZ), and (100%FZ,0%CZ), and it was found that the zeolite has bozzolanic effect, the optimum replacement amount of natural zeolite were determined to be 50% for FZ and 50% for CZ with compressive strength 28Mpa after 28 days and density 1830kg/m³, and this is enough to produce structural lightweight concrete. In this research, a comprehensive study is conducted on mechanical properties of structural lightweight concrete that contain various types of lightweight aggregates (pumice as coarse aggregate, and zeolite as coarse and fine aggregate), in addition, the investigation was about the structural behaviour of lightweight concrete beams produced by these types of aggregates the study this type of concrete meets the requirements of the construction sector due to its combined benefits of lightweight and high strength in relation to density.

2 EXPERIMENTAL WORKS

2.1 Concrete Mixtures

Two groups of lightweight concrete mixes were cast. The first group was four lightweight concrete mixes had a ascending gradual portion of weight between the coarse and fine zeolite {CZ60%:FZ40%,CZ50%:FZ50%, CZ40%:FZ60%,and CZ20%:FZ80%}, the water-cement ratio (w/c=0.8) and cement content (400 kg/m³) in addition to Super-plasticizer dosage (5% by weight of cement) were kept constant for all mixtures of this group, Fine and coarse zeolite aggregates were heated at 550 °C for two hours in the oven of the National Center for Housing and Building Research, in order to activate the surface of the zeolite to supply the concrete with air bubbles and increase the concrete volume[17]. The zeolite was left until it reached room temperature and then used in concrete mixtures. While the second group was four lightweight concrete mixes had a ascending gradual portion of weight between the coarse pumice and normal coarse aggregate { P50%:D50%, P65%:D35%, P75%:D25%, and P100%:D0% }, normal weight fine aggregate content (0.45m³), water-cement ratio (w/c=0.35), and cement content (400 kg/m³), in addition to Super-plasticizer dosage (2.5% by weight of cement) were kept constant for all mixtures of this group. in addition to a normal weight concrete mixture (NWC) for comparison with the concrete mixes in the first and second groups. Table (1) shows the components of concrete mixes.

Table (1): Mixing Proportions For 1m³ of LWC And NWC Specimens.

Mix symbol	Cement kg/m³	Water kg/m³	S.P kg/m³	Sand kg/m³	Zeolite kg/m³		Pumice kg/m³	Dolomite kg/m³
					Fine	coarse		
NWC(control)	380	228	0	680	0	0	0	1040
CZ60%:FZ40%	400	320	20	0	759	506	0	0
CZ50%:FZ50%	400	320	20	0	633	633	0	0
CZ40%:FZ60%	400	320	20	0	506	759	0	0
CZ20%:FZ80%	400	320	20	0	253	1012	0	0
P50%:D50%	400	140	10	747	0	0	170	577
P65%:D35%	400	140	10	747	0	0	222	408
P75%:D25%	400	140	10	747	0	0	258	292
P100%:D0%	400	140	10	747	0	0	348	0

Note:- CZ: Coarse zeolite aggregate, FZ: Fine zeolite aggregate, P: Pumice, D: Dolomite, S.P: Super-plasticizer

2.2 Used Materials

In this section, properties of used materials in this research are described which include cement, coarse pumice, coarse zeolite, fine zeolite, normal weight aggregates, natural sand, reinforcing steel, superplasticizer, and water.

2.2.1 Ordinary Portland Cement

In all prepared concrete mixes ordinary Portland cement (I , 42.5N) of 3.15 specific gravity was used. The mechanical and physical properties of the cement used are given in Table (2).

Table (2): The Mechanical and Physical Properties 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 more than 60
	Final	180	------------

2.2.2 Coarse Aggregate(Dolomite)

The used coarse aggregate was crushed dolomite with a nominal maximum size of 14 mm. The used crushed dolomite was examined according to the Egyptian guide for Laboratory Tests [18]. The characteristics of dolomite used are displayed in Table (3), whereas the grading of the dolomite is exhibited in Figure (1).

Table (3): The Characteristics of Crushed Dolomite.

Property	Result
Bulk density(kg/m³)	1.700
Specific gravity	2.6
Water absorption (%)	2.19

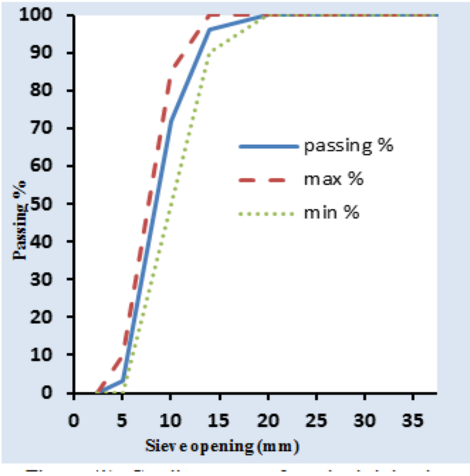

Figure (1): Grading curve of crushed dolomite

2.2.3 Coarse Aggregate(pumice)

The used coarse lightweight aggregate (LWA) was natural pumice aggregate passing from 14 mm sieve and retained on 5 mm sieve. Table (4) shows the chlorides and sulphates content before and after soaking and washing processes. The characteristics of pumice used are given in Table (5). While, the sieve analysis of pumice aggregate is given in Figure (2).

Table (4): Chlorides and Sulphates Content in Pumice.

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

Table (5): The Characteristics of Pumice.

Property	Result
Bulk density (Kg/m³)	500
Specific gravity	0.8
Water absorption (%)	16

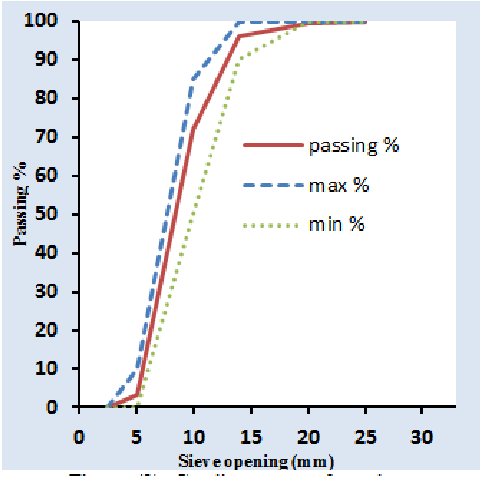

Figure (2): Grading curve of pumice

2.2.4 Coarse Aggregate(Zeolite)

Coarse zeolite (CZ) used as coarse aggregates with maximum nominal size of 14 mm and specific gravity of 2.2. The characteristics of coarse zeolite used are given in Table (6). While, the grading of coarse zeolite is given in Figure (3).

Table (6): The Characteristics of Coarse Zeolite.

Property	Result
Bulk density(kg/m³)	960
Specific gravity	2.2
Water absorption (%)	14

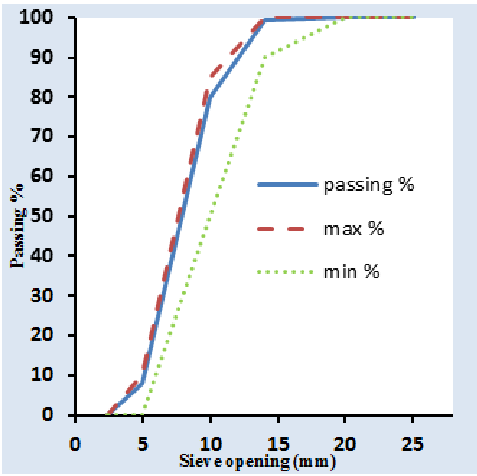

Figure (3): Grading curve of coarse zeolite

2.2.5Fine Aggregate(Sand)

The used fine aggregates was local natural sand. the used sand was tested according to the Egyptian guide for Laboratory Tests [18]. The characteristics of used sand are displayed in Table (7), whereas the grading of the sand is exhibited in Figure (4).

Table (7): The Characteristics of Sand.

Property	Result	Limits
Bulk density (Kg/m³)	1660	--------
Specific gravity	2.5	--------
Clay and fine materials (%)	0.6	_< 4%
Chlorides (%)	0.038	Not more than 0.06
Sulphates (%)	0.063	Not more than 0.4

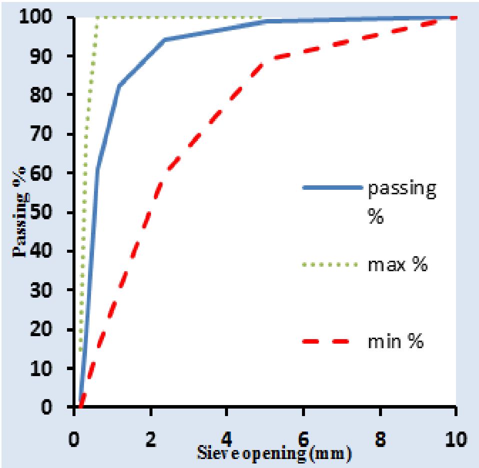

Figure (4): Grading curve of sand

2.2.6 Fine Aggregate(Zeolite)

Fine zeolite (ZF) used as fine aggregates with bulk density 960 kg/m^3 and specific gravity of 2.25. Chemical analysis of zeolite represented in Table (8). The characteristics of fine zeolite used are given in Table (9). Sieving analysis of the fine aggregates is presented in Figure (5).

Table (8): The Chemical Analysis of Zeolite.

Element	SiO_2	Fe_2O_3	Al_2O_3	CaO	K_2O	TiO_2	MgO	MnO	P_2O_5	Na_2O	L.O.I
Content %	67.11	3.14	13.01	2.87	3.17	0.29	0.51	0.11	0.02	1.3	8.22

Table (9): The Characteristics of Fine Zeolite

Property	Result
Bulk density(kg/m³)	960
Specific gravity	2.25
Fineness modulus	3.75

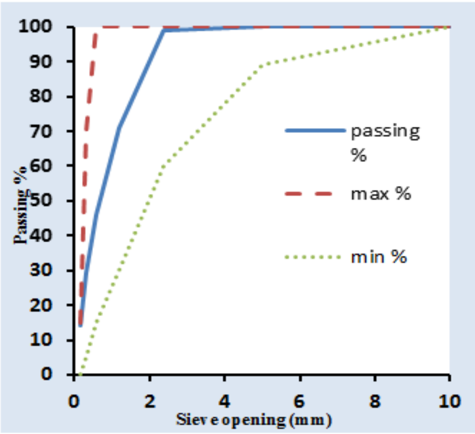

Figure (5): Sieve analysis of fine zeolite aggregate

2.2.7 Chemical Admixture

The superplasticizer utilized is Sikament –NN from sika Egypt company to improve the workability of concrete as per ASTM C-494 type F, the chemical and physical properties of Sikament –NN show in table (10).

Table (10): The Chemical and Physical Properties of Sikament NN

Chemical Base	Naphthalene Formaldehyde Sulphonate.
Appearance / Colour	Brown liquid
Density	(at 20°C) 1.200(ASTM C494)

2.2.8 Water

The water, which was used in the mix design and curing concrete, is portable water. The exporter of this water was the water-supply network system.

3 CONCRETE TESTS :

Investigations of all prepared concrete mixtures were carried out according to the following specifications:

A. The slump test was conducted on all fresh concrete mixes according to ASTM C143/143M[19]. Figure (6. A) shows the slump test.

B. The density of the concrete samples was recorded after 28 days according to (ASTM C 642-13)[20].

C. 81cubes (150*150*150mm) were prepared to carry out the compressive strength test after 7,28, and 56 days according to ECP 203-2016[21]. Figure (6. B) shows the compressive strength test.

D. Cylindrical samples(150mm diameter and 300mm height) were prepared for conducting splitting tensile strength test after 28 days according to ECP 203-2016[21]. Figure (6. C) shows the splitting tensile strength test.

E. The flexural strength test was carried out using four-point bending test, samples (100*100*500mm) were tested after 28 days according to ECP 203-2016[21].Figure (6. D) shows the flexural strength test.

F. The pull-out strength test method was used to evaluate bonding strength between steel and concrete according to ASTM C 900 – 01 [22].Figure (6. E) shows the pull-out strength test.

G. Cylindrical samples (150mm diameter and 300mm height) are prepared for implementing the modulus of elasticity test according to ACI 318-08[23]. Figure (6. F) shows the modulus of elasticity of concrete test.

H. the sorptivity test was carried out on cylindrical specimens (100mm diameter and 50mm height) according to ASTM C1585-04 [24].Figure (6. G) shows the procedure details of the sorptivity test.

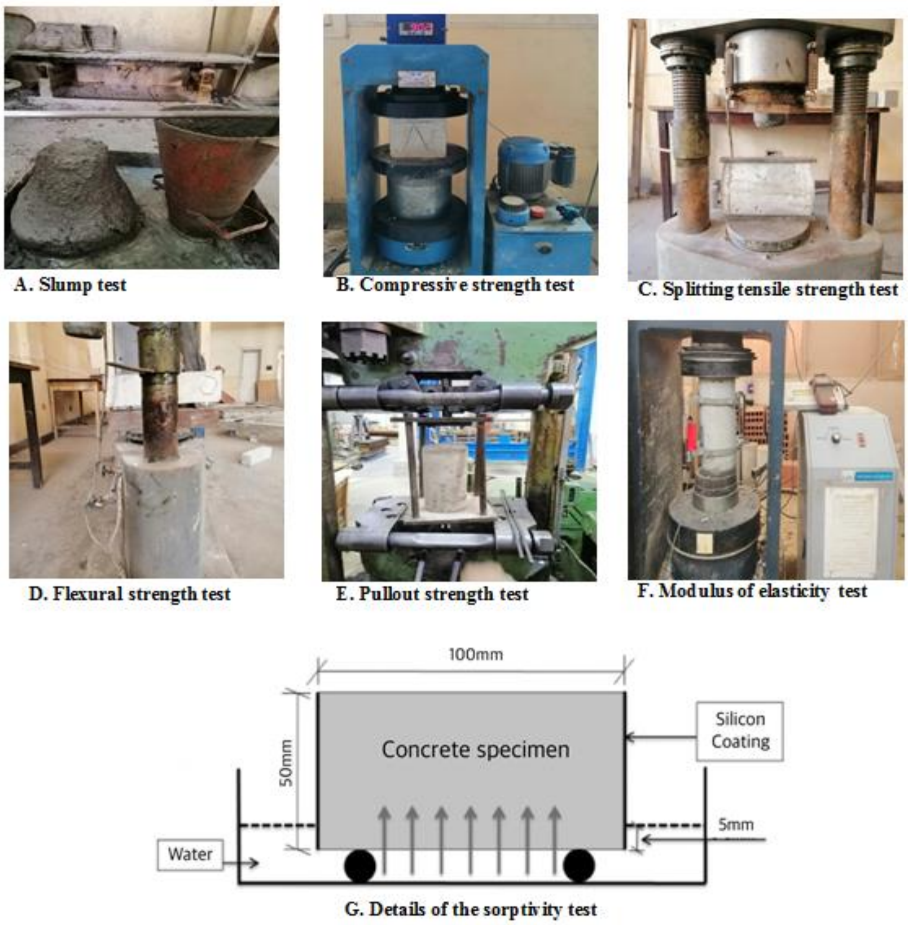

Figure (6): The concrete specimens tests.

4 PREPARATION OF REINFORCED CONCRETE BEAMS :

Three reinforced concrete beams with length (L) 2000mm, breadth (B) 100mm and height (H) 250mm and 15mm cover over reinforcement were prepared as shown in Figure (7. A), one beam of zeolite mixtures and the other one of pumice mixtures of similar densities in laboratory along with control beam, to determine the flexural behaviour of (SLWC) beams and compare it with the flexural behaviour of (NWC) beam. used 2Ø12mm diameter bars as tension reinforcement at bottom and 2Ø8mm diameter bars as compression reinforcement at top with reinforcement bars of diameter Ø8mm@100mm c/c as stirrups as shown in Figure (7. B). During casting, strains gauge was fixed on the main reinforcement at middle of beam. the beams were loading in flexural under four-point (simply supported) loading condition, and the simple supports were located 100mm from each end of the beam; that is, the clear span length was 1800mm. A steel distribution beam was installed between the test beam specimen and the actuator to distribute the single point load into two point loads. the two loads were applied 300mm from the midspan through the steel distribution beam using a calibrated hydraulic jack (30 tons). The LVTD was placed in the midspan and between the loading points to measure the beam deflection. in addition to, the strain gauge for concrete was placed on the upper surface of the beam. Figure (7. C) shows the beam during testing, while Figure (7. D) shows the set-up for tested beams.

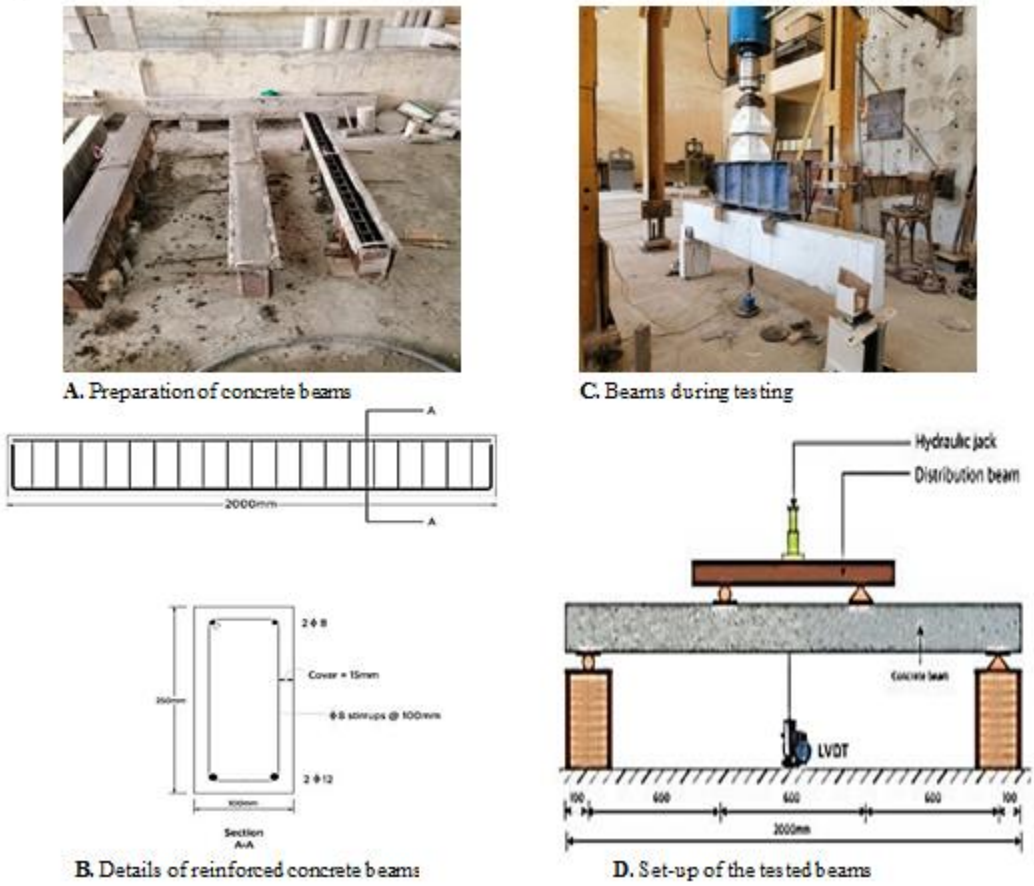

Figure (7): Preparing and testing concrete beams

5 RESULTS AND DISCUSSION

5.1 Fresh Properties

5.1.1 Workability

Workability of concrete describes how easily freshly mixed concrete can be mixed, placed, consolidated, and finished with minimal loss of homogeneity. Workability is a property that directly impacts strength, quality, appearance, and finishing operations.Results in Figure (8) describes changing in concrete workability expressed in Slump (mm), Results represented that slump of the concrete decreases with increasing of fine zeolite proportion from 115 mm in control concrete (NWC-Control) to 80mm in concrete contained 80% of fine zeolite aggregate (CZ20%,FZ80%). In general, the use of zeolite aggregate in concrete reduces the slump of the mixture, especially the fine zeolite because its voracious for water absorption. While, Results in Figure (9) described workability variation with increasing of coarse pumice proportion in concrete mixture. Results represented that slump of the concrete decreases with increasing of coarse pumice proportion from 115 mm in control concrete (NWC-Control) to 60mm in concrete contained 100% of pumice aggregate (pumice100%, dolomite0%). as a result of the increase in ratio of coarse pumice to dolomite, the slump values decreased, since pumice increase water absorbance due to its porous structure.

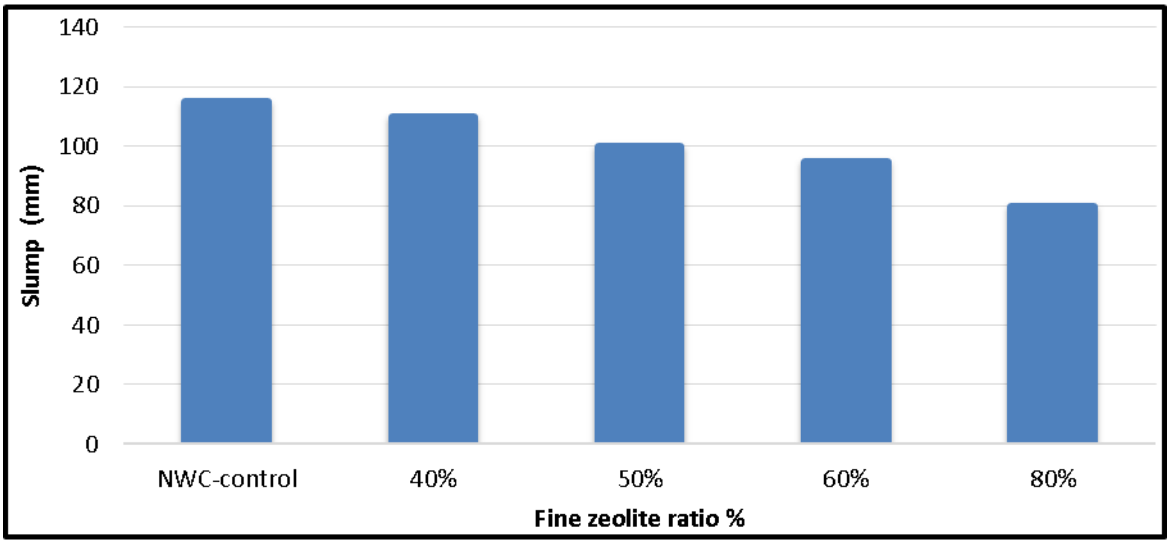

Figure (8): The relationship between Slump and fine zeolite ratio compared with normal weight concrete

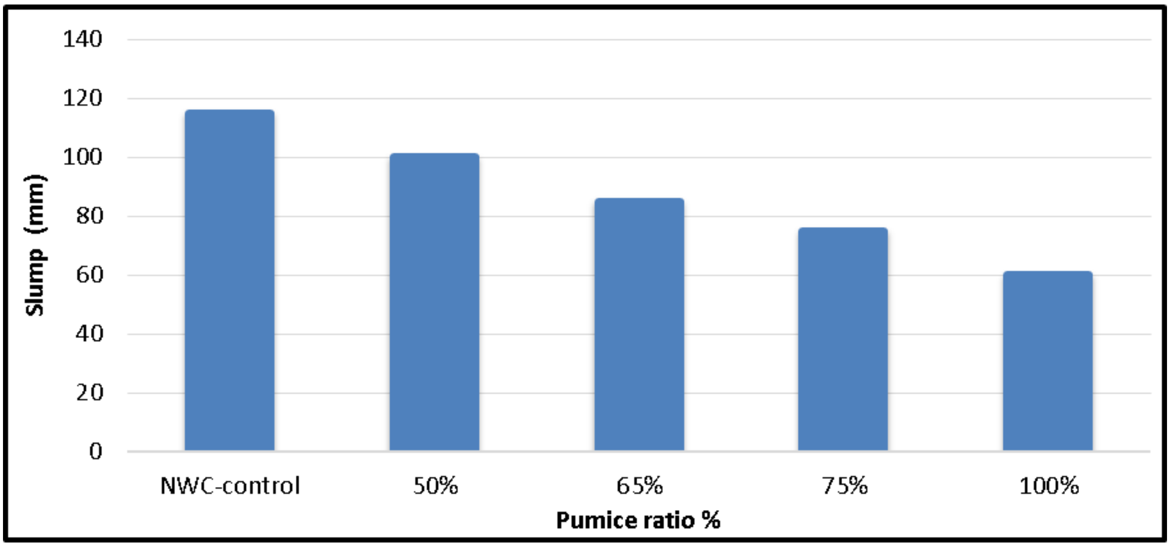

Figure (9): The relationship between slump and pumice ratio compared with normal weight concrete

5.2 Hardened Properties

5.2.1 Unit Weight

Unit weight is one of the main characteristics on which the classification of structural lightweight concrete depends. Results in Figure (10) indicated the variation in unit weight of the concrete with increasing of fine zeolite proportion. The unit weight of the concrete decreased from 2300 kg/m³ in normal weight concrete (NWC-Control) to 1775 kg/m³in concrete contained 80% of fine zeolite aggregate (CZ20%:FZ80%). the use of zeolite aggregate, regardless if its coarse or fine, it leads to decrease the unit weight of concrete, as a result to low specific gravities of calcined zeolite aggregate. While, Results displayed in Figure (11) showed variation of concrete unit weight with variation of pumice proportions to dolomite. Results showed decreasing in unit weight of the concrete with increasing of pumice aggregates percentage as it decreases gradually from 2300 kg/m³ in normal weight concrete (NWC-Control) to 1515 kg/m³ in concrete contained 100% of pumice aggregate (pumice100%,dolomite0%). Replacing dolomite aggregate with pumice aggregate reduces the unit weight of concrete by about (14 – 34%) compared to the normal weight concrete (NWC).

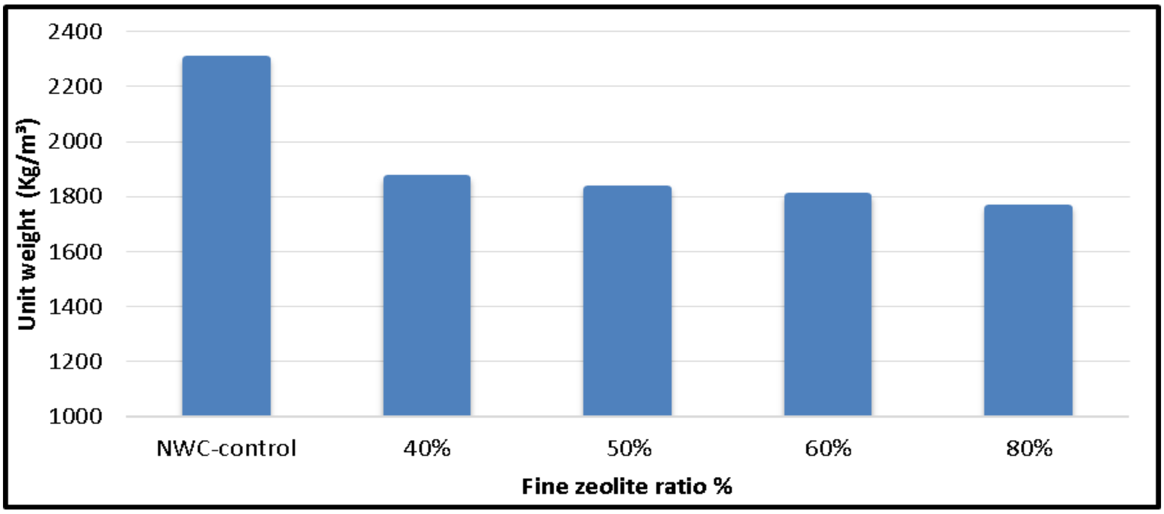

Figure (10): The relationship between unit weight and fine zeolite ratio compared with normal weight concrete

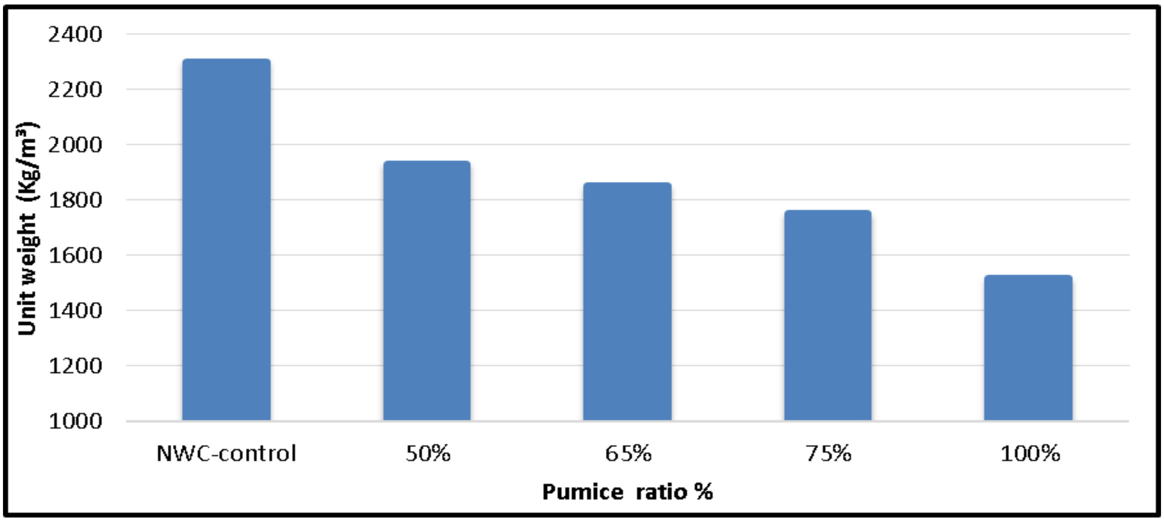

Figure (11): The relationship between unit weight and pumice ratio compared with normal weight concrete

5.2.2Compressive Strength

compressive strength is one of the main characteristics on which the classification of structural lightweight concrete depends. According to most codes, the compressive strength of structural lightweight concrete should be at least 17 Mpa after 28 day. Figure (12) shows the relation between compressive strength test results for prepared mixtures at the age of 7, 28, and 56 days and fine zeolite content, results indicated that compressive strength decreased by increasing fine zeolite content in concrete compared with normal weight concrete (NWC). Generally, the compressive strength of concrete decreased with increasing proportion of fine zeolite, comparatively higher strength values were measured for zeolite concrete at later ages, this is due to the pozzolanic effect of zeolite. In cement chemistry, it is usually accepted that the principle products of the hydration of Portland cement are amorphous calcium-silica-hydrate (C-S-H) 60% to 70%, portlandite $Ca(OH)_2$ 20% to 25% and other secondary phases, such as calcium carbonate[25]. Zeolite has a pozzolanic influence. Subsequently, through the hydration of cement, it readily reacts with Ca $(OH)_2$ (CH) and transform into the components that have cementitious features. As a result, the strength of hardened concrete is improved. The lower strength values determined at 7days are thought to be an incomplete reaction between zeolite and portlandite, due to the retardant effect of pozzolanic materials[16]. In addition to, internal curing of zeolite aggregate can enhance strength of concrete at later ages[26]. While, Figure (13) shows the compressive strength test results for prepared mixtures at the age of 7, 28, and 56 days, results indicated that compressive strength decreased by increasing pumice content in concrete by 21% in average with an increase pumice content from 0% to 100%, due to the porous structure of pumice aggregate, Generally, pumice aggregate enhanced the compressive strength of concrete at later ages this is due to the internal curing of pumice aggregate. so that the porosity of pumice aggregate provides a source of water for internal curing of the concrete that provides continued enhancement of concrete strength and durability[27].

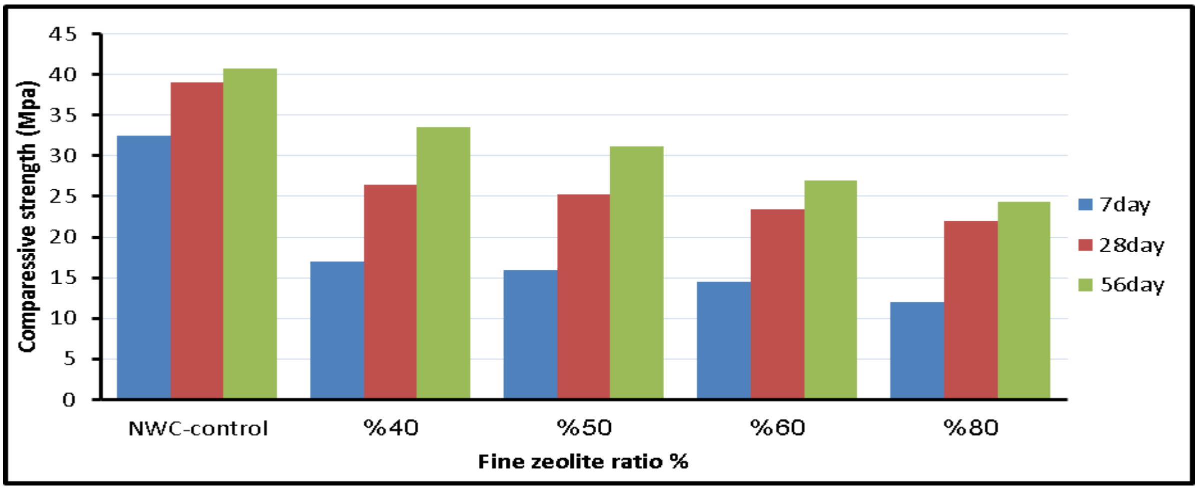

Figure (12): The relationship between compressive strength and fine zeolite ratio compared with normal weight concrete

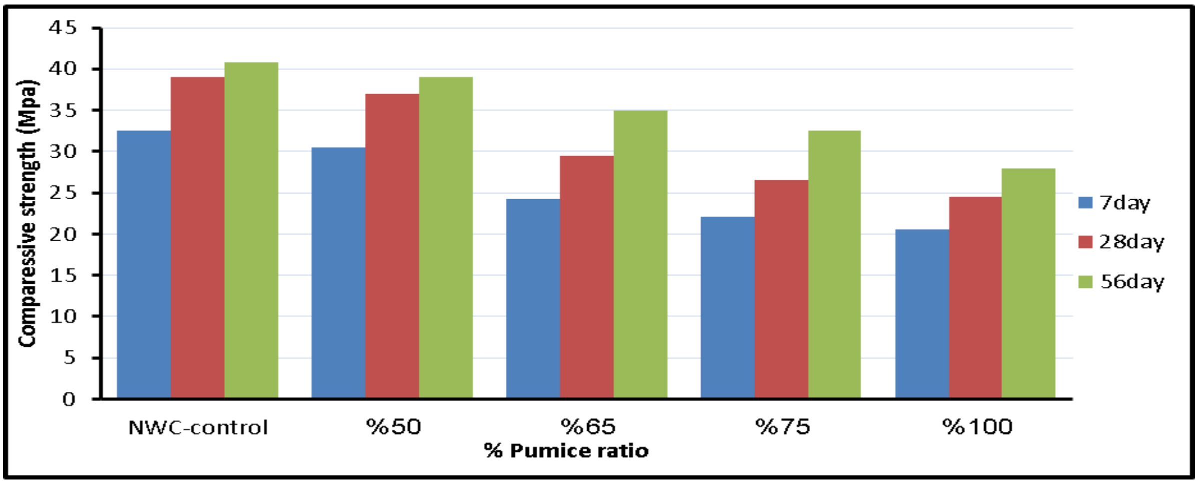

Figure (13): The relationship between compressive strength and pumice ratio compared with normal weight concrete

5.2.3Splitting Tensile Strength, Flexural Strength, And Pullout Strength

The concrete specimens were examined at the age of 28 days of curing, to determine the mechanical strength. The mechanical strength test results of (ZLWC) mixtures versus the control mixture (NWC-Control) are presented in Table (11), the results showed that the mechanical strength of (ZLWC) mixtures tended in the same direction as the compressive strength results, (ZLWC) mixtures reached 66% of splitting tensile strength, 63% of flexural strength and 61% of Pullout strength compared with control concrete (NWC-Control). While the mechanical strength test results of (PLWC) mixtures versus the control mixture (NWC-Control) are presented in Table (12), the results showed that the mechanical strength of (PLWC) mixtures tended in the same direction as the compressive strength results, (ZLWC) mixtures reached 95% of splitting tensile strength, 98% of flexural strength and 94% of Pullout strength compared with control concrete (NWC-Control).

Table (11): The Mechanical Strength of ZLWC Versus NWC-Control.

Mix No	Mechanical Strength at 28 Days (Mpa)		
	Splitting tensile strength	Flexural strength	Pullout strength
NWC(Control)	4.1	7.7	11.14
CZ60%:FZ40%	2.7	4.8	6.8
CZ50%:FZ50%	2.5	4.3	6.2
CZ40%:FZ60%	2.15	3.9	5.3
CZ20%:FZ80%	1.9	3.58	4.6

Table (12): The Mechanical Strength of PLWC Versus NWC-Control.

Mix No	Mechanical Strength at 28 Days (Mpa)		
	Splitting tensile strength	Flexural strength	Pullout strength
NWC(Control)	4.1	7.7	11.14
P50%:D50%	3.91	7.55	10.44
P65%:D35%	3	6.3	8.5
P75%:D25%	2.71	5.8	7.92
P100%:D0%	2.32	4.85	6.9

5.2.3 Modulus of Elasticity

Accurate prediction of modulus of elasticity of concrete is important in reinforced and pre-stressed concrete structures while calculating member deformations[28]. The elasticity calculated in this study is for 45% of the maximum stress. Figure (14) shows the stress-strain curves for the different percentages of (ZLWC) mixtures, results indicate a decreased modulus of elasticity with an increased percentage of fine zeolite, the modulus of elasticity decreased by increasing the fine zeolite content from (27% to 40%) compared with normal weight concrete (NWC-Control). Generally, (ZLWC) mixtures exhibits higher strains than normal weight concrete, due to the ability of calcined zeolite to form bubbles, which leads to a low modulus of elasticity. While Figure (15) shows the stress-strain curves for the different percentages of (PLWC) mixtures, results indicate a decreased modulus of elasticity with an increased replacement percentage of pumice, the modulus of elasticity decreased by increasing the pumice content from (1.6% to 19%) compared with normal weight concrete (NWC-Control). Generally, the use of pumice aggregate in concrete resulted in enhancing the modulus of elasticity, due to the high ductile nature of pumice aggregate.

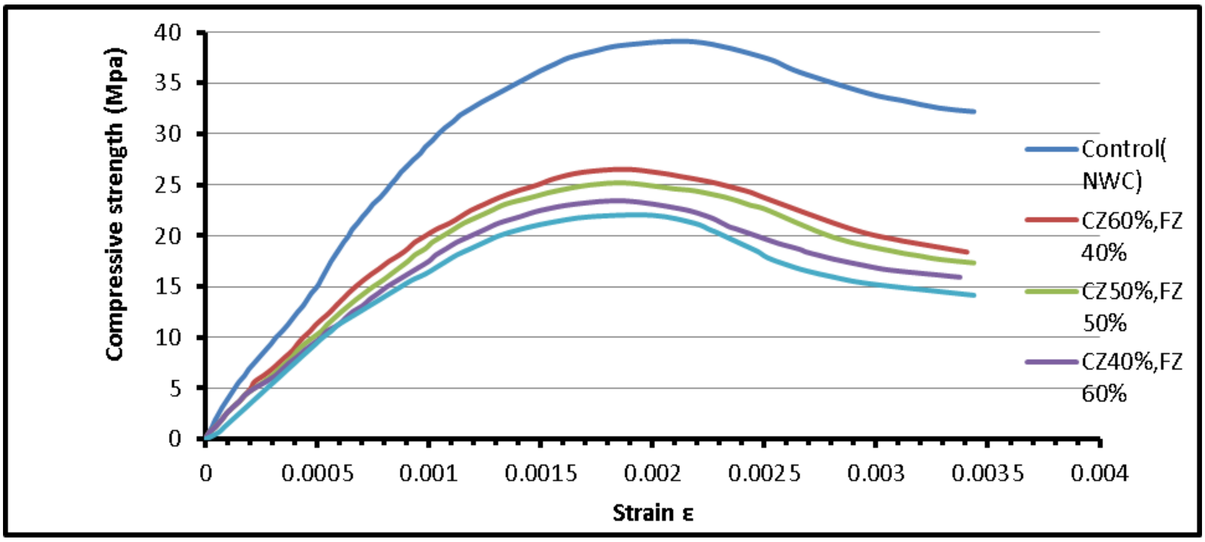

Figure (14): The relationship between modulus of elasticity and ZLWC versus NWC-Control

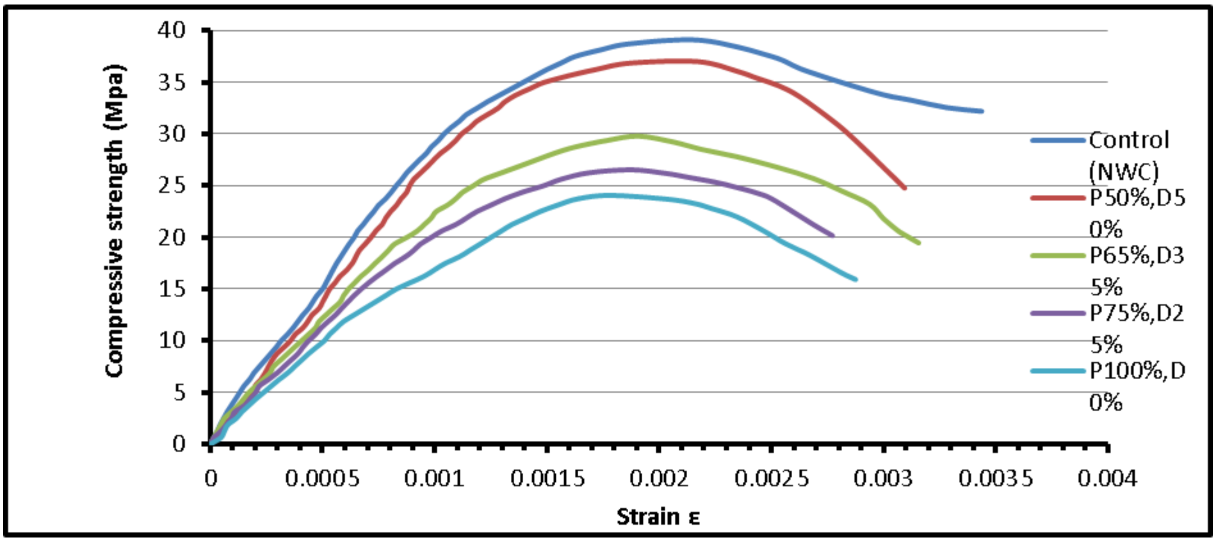

Figure (15): The relationship between modulus of elasticity and PLWC versus NWC-Control

5.2.4 Sorpativity

Sorptivity is used to determine the concrete capability to convey and absorb water using capillary suction. A reduction in sorptivity is a strong indication of durability improvement[29]. Figure (16) shows the relation between increasing in fine zeolite proportion in the produced concrete and the water absorption rate, while, Figure (17) shows the sorpativity test results, the results showed that the rate of concrete absorption increases with the increasing in fine zeolite proportion, The absorption rate of (ZLWC) mixtures increased by (33.75 to 51.5%) with increasing fine zeolite percentage compared to normal weight concrete. While, Figure (18) describes influence of pumice replacement proportion in the concrete on the absorption rate, While, Figure (19) shows the sorpativity test results, the results showed that the rate of concrete absorption increases with the increasing pumice replacement proportion, The absorption rate of (PLWC) mixtures increased by (10.5 to 43.9%) with increasing pumice percentage compared to normal weight concrete. Mohamed et al.[30] found that the use of lightweight aggregates in concrete increases the absorption rate since (LWAs) has a relatively higher porosity than (NWAs).

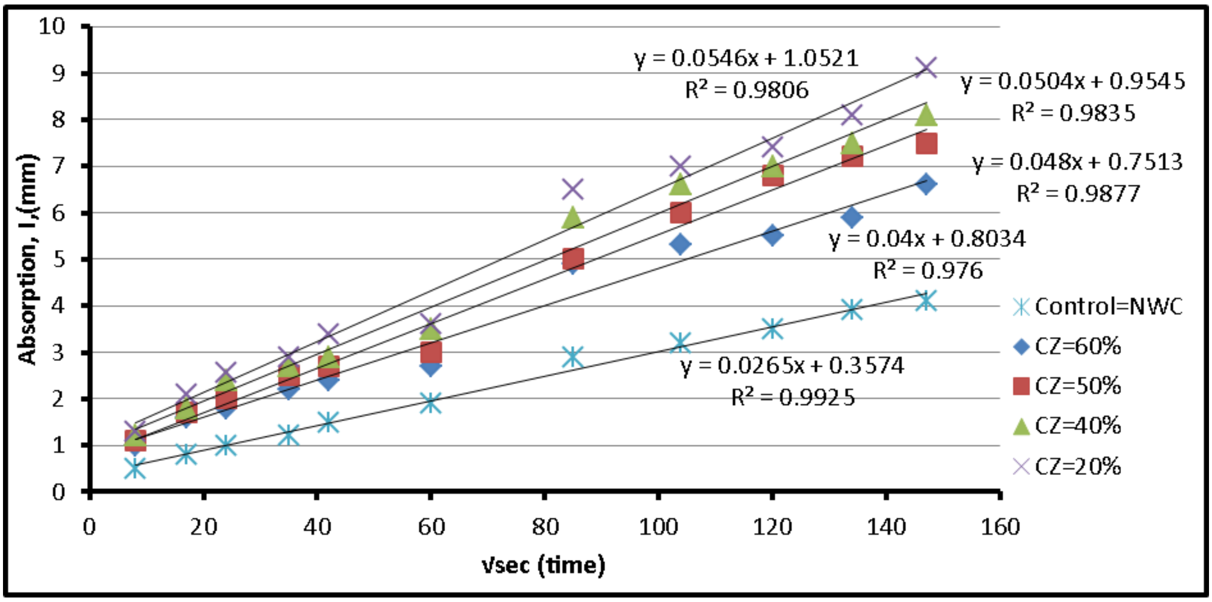

Figure (16): The absorption of ZLWC versus NWC-Control

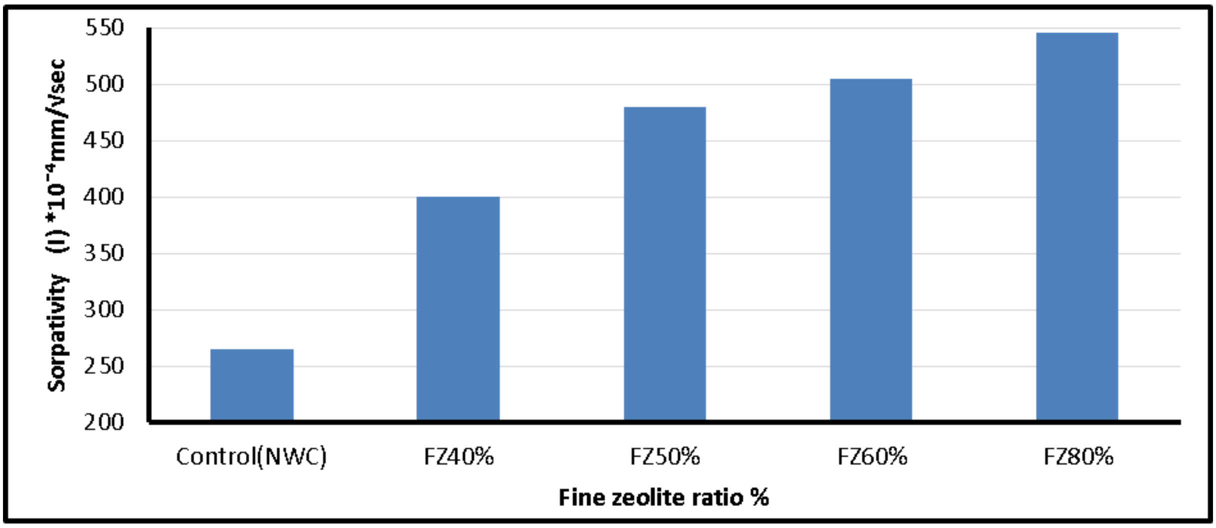

Figure (17): The sorpativity of ZLWC versus NWC-Control

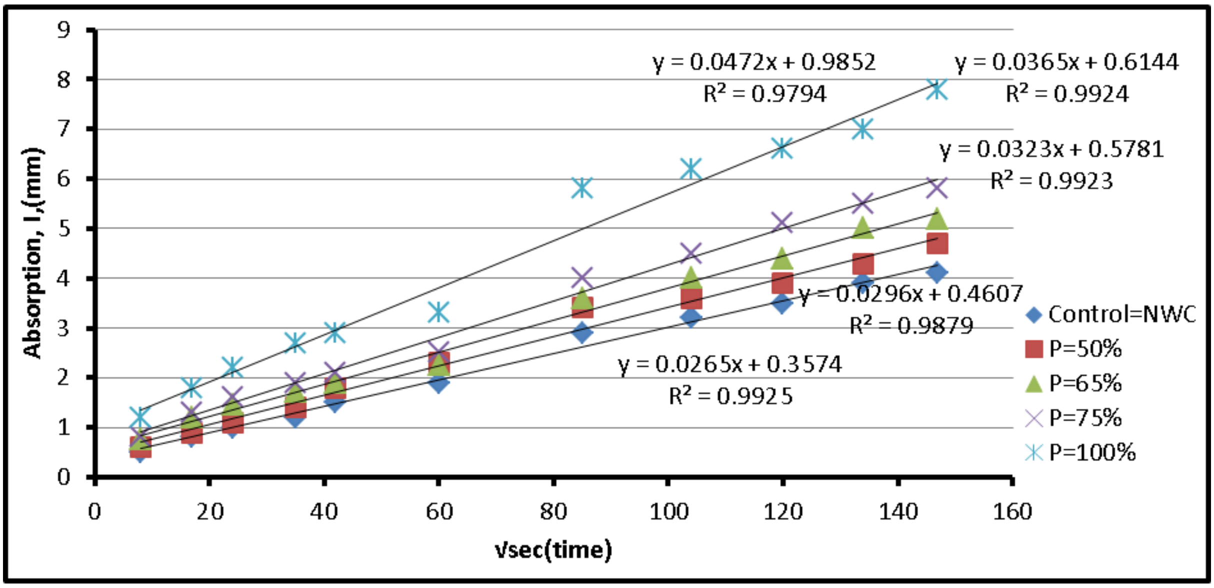

Figure (18): The absorption of PLWC versus NWC-Control

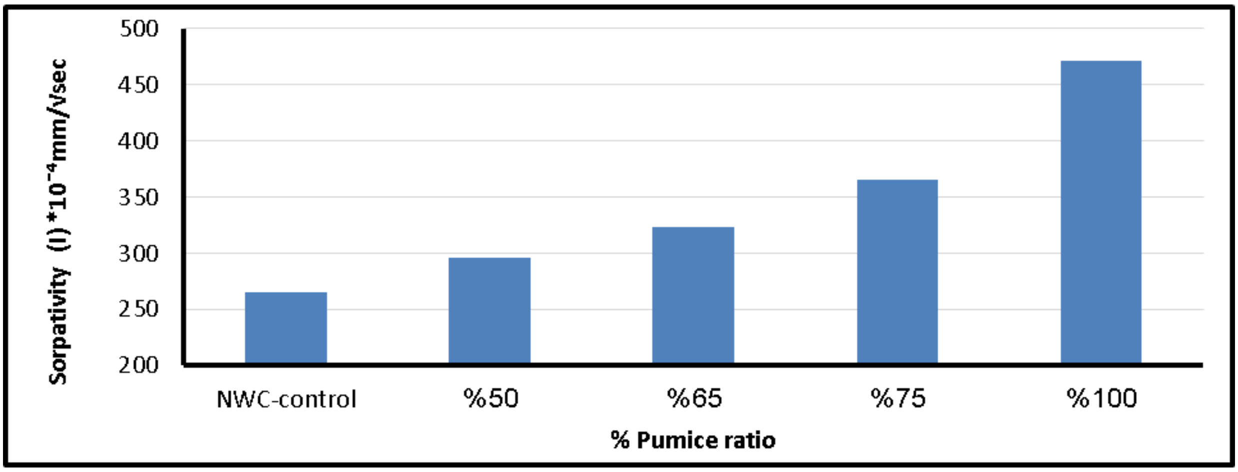

Figure (19): The sorpativity of PLWC versus NWC-Control

5.2.5 Application of Structural Lightweight Concrete

In order to develop lightweight concrete for structural applications, the flexural behaviour of three reinforced concrete beams was studied, one beam of zeolite mixture (CZ60%,FZ40%) and the other of pumice mixture (pumice65%, dolomite35%) of similar densities and compare it with the flexural behaviour of normal weight concrete beam (NWC-Control). Figure (20) shows the central deflection load of beams tested under two point-loading, found that for all beams the load tended to increase sharply with deflection, the relationship was still approximately linear until the steel started yielding. Beyond the yield point there was a large increase in deflection associated with a small increase in load. The flexural behaviour was almost the same for all beams and the type of failure observed is flexural failure. The maximum load of the normal weight concrete beam (NWC-Control) was recorded 100KN and corresponding deflection 30mm, and for lightweight pumice concrete beam (Pumice65%,Dolomite35%) was recorded 95KN and corresponding deflection 28mm, and for lightweight zeolite concrete beam (CZ60%,FZ40%) was recorded 93KN and corresponding deflection 23.5mm. The first crack appeared in normal weight concrete beam (NWC-Control) at 30KN loading, and in pumice concrete beam (Pumice65%, Dolomite35%) at 25KN loading, and in zeolite concrete beam (CZ60%, FZ40%) at 20KN loading.

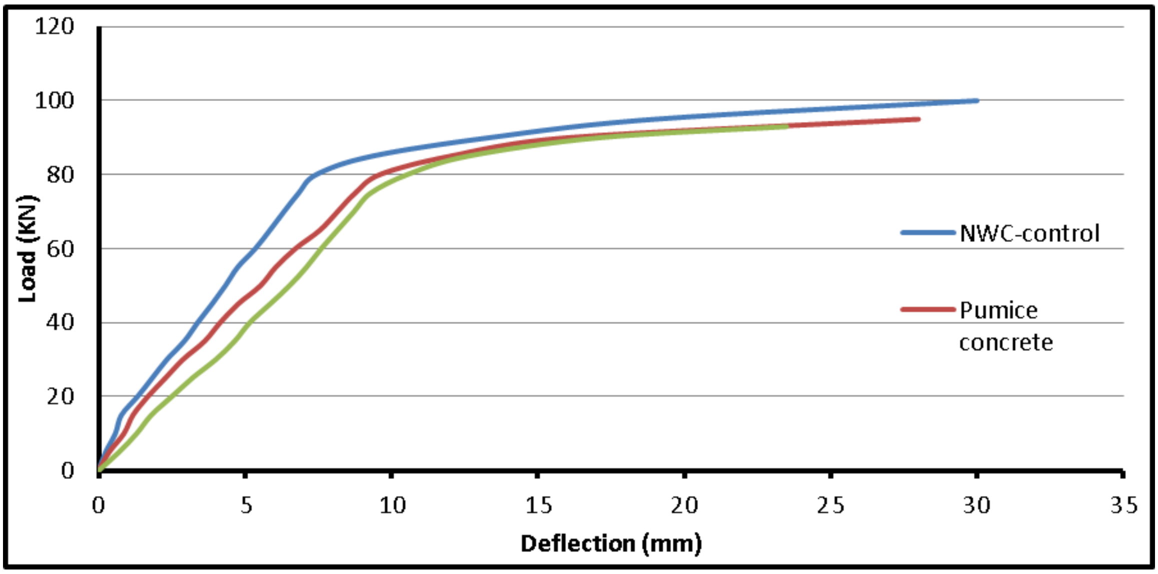

Figure (20): The relationship between load-deflection curve for SLWC versus NWC

6. CONCLUSIONS

From the previous tests and analyses, the following conclusions were reached**:**

- The workability of zeolite mixtures decreased with increasing the percentage of fine zeolite.
- The workability of the pumice mixtures decreased with the increase in the pumice replacement percentage.
- The LWA (zeolite & pumice) caused more water to be absorbed, resulting in lower workability despite the use of a superplasticizer.
- Increasing the percentage of fine zeolite leads to a decrease in the unit weight of zeolite mixtures.
- The unit weight of pumice mixtures decreased with the increase in the pumice replacement percentage.
- Based on the unit weight results, all mixtures (zeolite & pumice) showed a unit weight less than 2000 Kg/m^3, which can be considered lightweight concrete according to ACI 213R-14.
- The compressive strength of zeolite mixtures decreased with increasing in the fine zeolite percentage.
- Increasing the pumice replacement percentage leads to a decrease in the compressive strength of pumice mixtures.
- The results of tensile strength, flexural strength, bond strength, and modulus of elasticity of all mixtures (zeolite & pumice) tended in the same direction as the compressive strength results.
- All mixtures (zeolite & pumice) showed high bond strength with steel reinforcement and failure in steel bars is always occurring.
- All mixtures (zeolite & pumice) achieved compressive strength higher than 17 Mpa after 28 days and unit weight less than 2000 Kg/m^3, which can be considered structural lightweight concrete according to ACI 213R-14.
- The sorpativity of all mixtures (zeolite & pumice) increased due to the porous structural of the LWA which provides a high suction property.
- lightweight concrete can be used for structural applications, as the effect of lightweight concrete on the flexural strength of the tested beams was not significant compared with normal weight concrete, the zeolite mixture and pumice mixture showed a slight decrease in the maximum load by 7% and 5% respectively, the failure mode of all beams was the same and the type of failure observed was flexural failure.

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