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EFFECT OF DIFFERENT TYPES OF LIGHTWEIGHT AGGREGATE ON STRENGTH AND MODULUS OF ELASTICITY OF CELLULAR CONCRETE

Suhad Mohammed Abd[1], *Dunay Khalil Ismail[2]

1) Assistant Prof., Civil Engineering Department, Diyala University, Diyala, Iraq.
2) MSc. student , Civil Engineering Department, Diyala University, Diyala, Iraq.

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Abstract: The objective of this study is to improve properties of structural foamed concretes by adding fine and coarse lightweight aggregate. The materials that used in this study were fly ash as fine material and various type of lightweight aggregate (Leca, porcelanite). The mechanical properties included fresh and hardened density, compressive strength and elasticity modulus were tested in this study. The results show increases in compressive strength and modulus of elasticity by increasing the percentage of fine aggregate (fly ash).The optimum percent is 50% for fine aggregate (fly ash).The compressive strength decreases with increasing the percentage of lightweight coarse aggregate .The modules of elasticity increases by increasing the replacement percentage of fly ash . The addition of lightweight coarse and fine aggregate affect on the percentage of foam need be added to the mix for the desired density. Type of aggregate have significant effect on compressive strength and modulus of elasticity for foamed concrete. Flyash increase in compressive strength about (39%). Light weight aggregate decrease in compressive strength about (2-50) %. Flyash increase in modulus of elasticity about (10-56)% and light weight aggregate increase in modulus of elasticity about (1-20)%. Fly ash and lightweight aggregate (Leca and Porcelanite) improved the properties of foamed concrete.

Keywords: *Foam concrete, lightweight aggregate, modulus of elasticity, Compressive strength.*

تأثير انواع مختلفة من الركام الخفيف الوزن على معامل المرونة ومقاومة الانضغاط للخرسانة الرغوية.

الخلاصة: الهدف من هده الدراسة هو تحسين خصائص الخرسانة الرغوية المستعملة لأغراض الانشائية بوجود الركام الناعم والركام الخشن خفيف الوزن. المواد المستخدمة في هذه الدراسة (ركام ناعم هو مسحوق الرماد المتطاير) ونوعين مختلفين من الركام الخشن (ليكا وبوريلسنايت). شملت الخواص الميكانيكية للاختبارات كثافة الطرية والصلبة ،مقاومة الانضغاط ومعامل المرونة. أظهرت النتائج ان مقاومة الانضغاط ومعامل المرونة في حالة وجود الركام الناعم تزداد مع زيادة نسبة الاستبدال للركام الناعم .أفضل نسبة للاستبدال من الركام الناعم(الرماد المتطاير) كانت 50% .تناقصت مقاومة الانضغاط مع زيادة نسب الركام الخشن .زاد معامل المرونة من زيادة نسب استبدال الركام الناعم (الرماد المتطاير) .الركام الناعم والخشن ساهم في تقليل رغوة الفوم في الخليط .نوع الركام يؤثر في مقاومة الانضغاط ومعامل المرونة للخرسانة الرغوية .كانت الزيادة في مقاومة الانضغاط للمسحوق الرماد المتطاير حوالي (39%)اما الركام الخشن كانت الزيادة في زيادة مقاومة الانضغاط تتراوح بين (1-20%) للنسب الاضافة من (0.2-0.4) . كانت الزيادة في معامل المرونة لمسحوق الرماد المتطاير تتراوح بين (10-56%) ونسبة زيادة الركام الخشن تتراوح بين (1-20) % . الرماد المتطاير والركام الخشن بكلا نوعيه (ليكا والبورسلينايت) حسن خصائص الخرسانة الرغوية .

*Corresponding Author dunyakh17@gmail.com

1. Introduction

Foam concrete is a type of lightweight concrete without aggregate just cementations materials with air voided [1].The main advantages of foamed concrete are sustainable and economically and friendly for environment .foamed concrete characterize by low compressive strength (1-10) MPa , which limit its use and applications, Therefore, Most researcher tried to improve mechanical properties to increase and expand its use in structural application specifically improving its compressive strength [2],[3].

. Jones and McCarthy 2005,b,[4], Kearsley and Wainwright 2000,2001a,[5],[6], Narayanan and Ramamurthy 2000a,b,2006[7][8]][9], Kunhanandan and Ramamurthy 2007a,b,2008 [10][11] [12], Ramamurthy et al. 2009 [13], They mention that strength can be increased by reducing water to binder and using silica fume and fly ash with ultra-fine silica.

Main important factors in the production of stable foamed concrete are selection foaming agent, aggregate, and water-cement ratio, design of mix, all these factors affect on fresh and hardened density properties [3]. In addition sand /cement ratio affect on foamed concrete show foamed concrete is produced with sand/binder proportions of 1:1to 4:1[14]. Jones, M. R., and A. McCarthy [15] made an extensive laboratory-based investigation into unprocessed low lime-fly ash in foamed concrete as a replacement for sand. It is reported that the strength of fly ash concrete was 3 times more than the sand concrete. More significantly, while the strength of sand mixes remained fairly constant beyond 28 days, those of fly ash foamed concrete at 56 and 180 days were up to 1.7 to 2.5 times higher than 28 days values, respectively.

Siddique[16] investigated for mechanical properties of normal concrete with various percentage of replacement class F fly ash by weight .the results showed that the compressive strength and modulus of elasticity of flyash improved as compared to control concrete. Increase partial replacement of fly ash from sand result in decreasing workability and need more quantity of superplasticizers to be added to concrete [15].

Hilal et al. [17], studied the observation of the addition of (silica fume and fly ash) which achieved higher compressive strength to density ratio compared with foamed control .Also using fly ash as replacement 50% from sand give highest compressive strength. A few researchers investigated the addition of aggregates to foamed concrete mix. Therefore, mechanical properties will be investigated with two types of lightweight aggregate named (porcelanite and Leca). The behavior of these coarse aggregates will be explained. Han-Seung Lee et. al [18], investigated the normal aggregate with foamed concrete which demonstrated that compression and modules of elasticity were in good agreement.

Hisham K. Ahmed et. al [19], Studied the addition of plastic fiber to lightweight foam concrete with coarse and fine aggregates using natural sand as a total replacement of fine porcelanite aggregate and with 2% foaming agent percentage, which resulted in the percentage of increase in density, ultrasonic pulse velocity, acoustic impedance, compressive strength, splitting tensile strength, flexural strength, and impact resistance .Y. J. Kum at el [20] found that improvement in compressive strength of foamed had lightweight aggregate more than light foamed concrete without aggregate.

2. Materials

2.1. Cement

The cement used in all concrete mixes was ordinary Portland cement made in Iraq by (TASLUJA-BAZIAN). The tests were conducted by the National Center of Laboratories and Researches .Table1, 2 shows the chemical and physical Properties of the Cement.

Table 1. Chemical composition and main compounds

Compound Composition	Chemical Composition	Percentage By Weight*	Limit of Iraqi Specification No.5/1984
Lime	CaO	61.19	-
Silica	SiO2	21.44	-
Alumina	Al2O3	4.51	-
Iron oxide	Fe2O3	3.68	-
Magnesia	MgO	2.31	5.0 (max)
Sulfate	SO3	2.7	2.8 (max)
Loss on ignition	L.O.I.	2.39	4.0 (max)
Insoluble residue	I.R.	1.18	1.5 (max)
Lime saturation factor	L.S.F.	0.87	(0.66-1.02)%
Main compounds (Bogue's equation)		Limit of Iraqi Specification No.5/1984	
Tricalcium Silicate	C3S	42.83	-
Dicalcium Silicate	C2S	29.4	-
Tricalcium Aluminate	C3A	5.73	-
Tetracalcium aluminoferrite	C4AF	11.19	-

Table 2. Chemical composition and main compounds

Physical Properties	Test result*	Limit of IOS 5:1984
Fineness using Blaine air permeability apparatus (m2/kg)	405	> 230
Soundness using autoclave method	Not available	< 0.8 %
Setting time using Vicat's instrument		
Initial (min)	135	> 45 min
Final (hrs.)	3.25	< 10 hr.
Compressive strength for cement paste cube (70.7 mm) at		
3 days (MPa)	24.4	>15
7 days (MPa)	32.3	> 23

2.2 Sand

Fine standard silica sand as fine aggregate was used .The specific gravity 2.60 of sand silica and grade practice was 600 μm.

2.3 Steel Fiber

The steel fiber used in this study is hooked-end low carbon produced by Sika. Type of steel Fiber was hooked-end with length 30mm and aspect ratio is 50, as shown in Fig.1.

2.4 Leca

Lightweight aggregate was classified as expanded clay as shown in Fig. 2 .This type was exposed to high temperature to create pyroclastic operations in the rotary kiln. The exposure extremely too high temperature led to the burning of the organic compounds. The aggregate is solid, non-combustible, environmentally friendly and lightweight. The tests were conducted by the National Center of Laboratories and Researches .The properties of the Leca aggregate as shown in Table 3.

Table 3.Properties of LECA aggregate

Properties	Quantity
Specific gravity	0.52
Bulk density in Loose state % voids	79.6%
Aggregate crushing test was	37.49%;
Compacted state % voids	69.01%
Fineness modulus was found to be	6.546.
Water absorption	16.5%

2.5 Porcelanite

The coarse aggregate used in this work was purchased from north of Al-Rutba town in Al-Anbar, Iraq. The color of Porcelanite a white-yellow as shown in Fig.2. Table .4 shows physical properties of Porcelanite aggregate which included high permeability, low density and the maximum size of 9.5 mm. The tests were conducted by the National Center of Laboratories and Researches.

Table 4. Physical Properties of porcelinite aggregate

Properties		Limits
Density (OD) –kg/m3	1447	ASTM C127-15
Density (SSD) –kg/m3	1860	
Apparent density - kg/m3	2397	
Relative density (specific gravity) OD	1.48	
Relative density (specific gravity) SSD	1.86	
Absorption %	32%	
Saturation %	3.6	
Loose bulk density (apparent) kg/m3	721	ASTM C29-09
Rodding bulk density (apparent)	791	
Dry loose unit weight - kg/m3	708	
Dry rodding unit weight - kg/m3	785	
Loose bulk density (apparent) kg/m3	891	
Rodding bulk density (apparent)	989	
Voids loose %	52	
Voids rodding %	47	

2.8 Silica fume

In this study, silica fume was used the ultra-fine material of 20000 m^2/kg.The spherical particles were less than (1 μm) in diameter. The specific gravity of silica fume is between 2.2 to 2.3. The density of silica 130 (unidentified) was 600 kg/m^3. Standard specifications for silica fume used in cementations mixtures are ASTM C1240 [24].

2.9 Superplasticizer

In this study, the superplasticizer for concrete and mortar is used which known a (Sika Viscocrete-5930). Its free chloride content and density 1.081kg/lt $\pm$ 0.05 at 25°C which satisfies the requirements for superplasticizer according to ASTM-C494Typos G and F [25].

2.6 Fly ash

In this study was used class F fly ash acquired from the thermal power plant at Bathinda in India. The Table 5 shows chemical composition of the flyash which was determined according to (ASTM C 618) [26] as shown as Fig.3.

Table 5. Properties of fly ash

Chemical analysis	Class F fly ash (%)	ASTM requirement C 618%
Silicon dioxide, SiO2	55	______
Aluminum oxide, Al2O3	26.1	______
Ferric oxide, Fe2O3	5.4	______
SiO2+Al2O3+Fe2O3	86	70.0 min
Calcium oxide, CaO	5.5	______
Magnesium oxide, MgO	2.4	5.0 max
Titanium oxide, TiO2	1.4	______
Potassium oxide, K2O	0.7	______
Sodium oxide, Na2O	0.43	1.5 max
Sulfur trioxide, SO3	1.38	5.0 max
LOI (1000 _C)	1.8	6.0 max
Moisture	0.32	3.0 max

2.7 Foaming agent type

Aercel from Sika Chemistry Factory which is chloride free was used to produce lightweight concrete by entraining a controlled amount of air bubbles to the concrete mix. Table.7 indicates the technical description of the foaming agent used throughout this investigation. The liquid was added to compress air to produce an agent with microbubble as shown in Fig.4. The proportions of foam mortar liter foam to 30-liter water in a foam generator.

Figure 1.Steel fiber

Figure 2. Lightweight aggregate

Figure3. fly ash

Figure 4.Foam mortar

3. Mix design

Twenty-one trial mixes were used in this study to determine the best design for the best mechanical properties of the mixture. The work was divided into two parts; part one add light aggregates for foamed concrete, with the different percentage for both types, the mixes listed in Table 6 .Part two replacement lightweight fine aggregate from sand the mixes listed in Table 7, the first mix (Foam control) was controlled for all mixes. The percentage of water-cement ratio constant for light aggregates 0.28% of cementations material, 8% superplasticizer, 10% Silica Fume and 0.4% steel fiber by for all mixtures. The density target of mixing was 1800∓50. The casting of samples as shown in Fig.4.

Table 6. Mix preposition of aggregate mixes

Group	Name	Cement Kg/m^3	sand Kg/m^3	coarse aggregate-Porcelanite Kg/m^3	Coarse aggregate-LECA Kg/m^3	Silica fume Kg/m^3	steel fibre Kg/m^3	w/c Kg/m^3	Sp Kg/m^3	Foam agent m^3
FC1	1:1	755	755	0	----	75.5	31	232.54	6.644	20%
G1 S:C 1:1	P 1:1.1:0.84	540	594	453.6	----	54	31	166.32	4.75	1%
	p 1:1.1:0.6	580	638	348	----	58	31	178.64	5.14	10%
G2 S:C 1:1.1	P-1:1:0.6	600	600	360	----	60	31	184.50	5.28	12%
	P1:1:0.4	640	640	256	----	64	31	197.12	5.63	15%
	P1:1:0.3	665	665	199.5	----	66.5	31	204.82	5.85	16%
	P1:1:0.25	675	675	168.75	----	67.5	31	207.90	5.94	17%
G1 S:C 1:1	LE-3 1:1.1:.4	590	649	----	236	59	31	181.72	4.543	5%
	LE-4 1:1.1:.35	600	660	----	210	60	31	184.80	4.6	6%
	LE-5 1:1.1:.25	640	704	----	160	64	31	197.12	4.90	7%
G2 S:C 1:1.1	LE-6 1:1:.35	610	610	----	187.88	61	31	187.88	4.70	6%
	LE-4 1:1:.4	620	620	----	248	62	31	190.96	4.77	5%

Table 7. Mix preposition of fly ash mixes

name	Cement kg/m3	Sand kg/m3	Fly ash kg/m3	Silica fume kg/m3	Water kg/m3	sp kg/m3	Steel fiber kg/m3	Foam kg/m3
FC1	698.52	776.13	------	77.61	217.32	6.21	31.20	22.3%
Fsh 100	621.36	------	690.40	69.04	386.62	11.05	31.20	1%
Fsh-.7	642.65	214.22	499.84	71.41	339.89	9.71	31.20	9%
Fsh -0.5	657.68	365.38	365.38	73.08	306.92	8.77	31.20	13%
Fsh-.45	661.55	404.28	330.77	73.51	298.43	8.53	31.20	13.6%
Fsh-0.3	673.43	523.78	224.48	74.83	272.36	7.78	31.20	16.6%
Fsh -.25	677.48	564.57	188.19	75.28	263.47	7.53	31.20	17%

4. Experimental work

4.1 Workability

Flow and slump tests were used to determined workability of mixes according to ASTM C1437 [26]. C143 [28] respectively as shown in Fig. 5.

4.2 *Dry density*

The density test passed through four stages. The first stage is the fresh during the mixing. The second and third stages are the hardening stages for 7 and 28 days, respectively. The final stage is the dry phase, which was conducted in an oven where the samples were placed at a temperature of 100 °C, thereby representing the reality of the concrete site. Three-cylinder (150*300) mm and cubes (100*100*100) mm were used to the determine the test of density

4.3 Compression test

Cubes of dimensions (100*100*100)mm and cylinder of 150mm diameters and 300mm height were casted to determine compressive strength test in 7 days and 28 days, after open the form, the specimens were placed in curing basin for one day .then wrapped in cling film for 28 days until test with 20°C. Fig.6 shows cube compression test machine. The compressive strength test was held according to ASTM C39 [29].

4.5 Modules of elasticity

A cylinder with a diameter of 150 mm and length of 300 mm was used to determine modulus of elasticity. Two strain gauges were used in mid-height cylinder to calculate strain in concrete and the modules from strain stress of concrete. The test procedure was performed according to ASTM C469 [30]. At 40% of the ultimate load. Fig. 6 explains the modules of elasticity test.

Figure.5 Test of Flow

Figure.6 Test of Modules Of Elasticity

4. Results and discussion

4.1 Flow

The flow was tested for mixtures based on the absence aggregate according to standard specifications of ASTM C-1437[27] and ASTM 1611[28].The mixture with Porcelanite was not compared with flow foam mix control because the tested of the mixtures had aggregate different from the mixture with foam mortar were tested they test with different method test ASTM C-1437.The results of fine aggregate show the decrease workabiltity with increase replacement percentage of fly ash from sand. The results show that mixture with Porcelanite aggregate had lower workability than those with Leca .The high absorption of water from the mixtures and shape of circular Leca led to more workability. Increased the value of sand to cement affect the flow of mix.The mixes had higher amount of sand led to higher workability. Fig.7, Fig. 8, and Fig. 9 show the test results of flow. In general, addition lightweight aggregate increases workability and increases sand binder led to increasing workability.

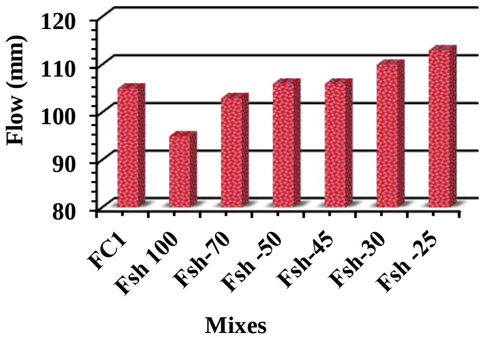

Figure.7 Results of Flow For Fly Ash

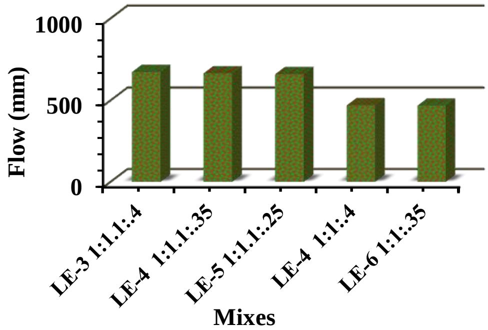

Figure.8 Results of Flow For LECA

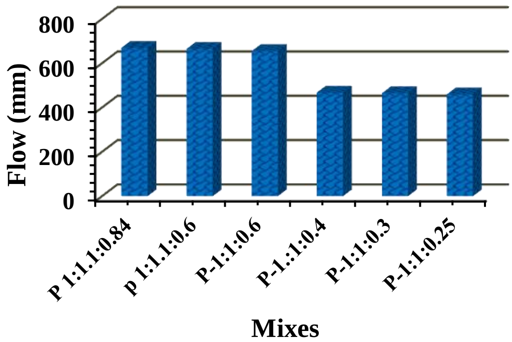

Figure.9 Results of Flow for Porcelanite

4.2 Density

The amount of foam was variable according to the mixing rates of the coarse aggregate because that the part of the decrease in weight can be attributed to the presence of light coarse aggregate in the mixture. Thus the foam was added until the required density connected to the target density is attained. The results showed that the high replacement percentage of fly ash from sand led to decrease density that due to the lightness of the particle size, high porosity and high absorption capacity of the of fly ash. Thus the high ratio additional aggregate has reduced the weight of lightweight aggregate due to the lightness of the particles of aggregate. The density of the foam concrete was reduced by increasing the percentage of foam in the mixture. The results showed that the density decreases with age due to amount loss of absorbed water. Fig.10, Fig.11, and Fig.12 show results of density at 7, 28 days test.

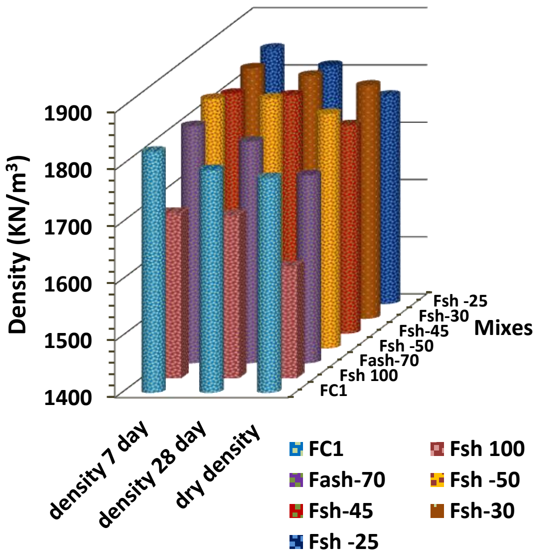

Figure10. Results of Densities for Fly Ash

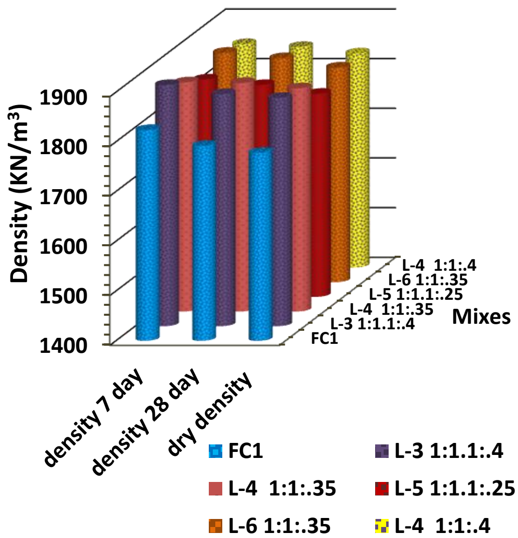

Figure .11 Results of Densities for LECA

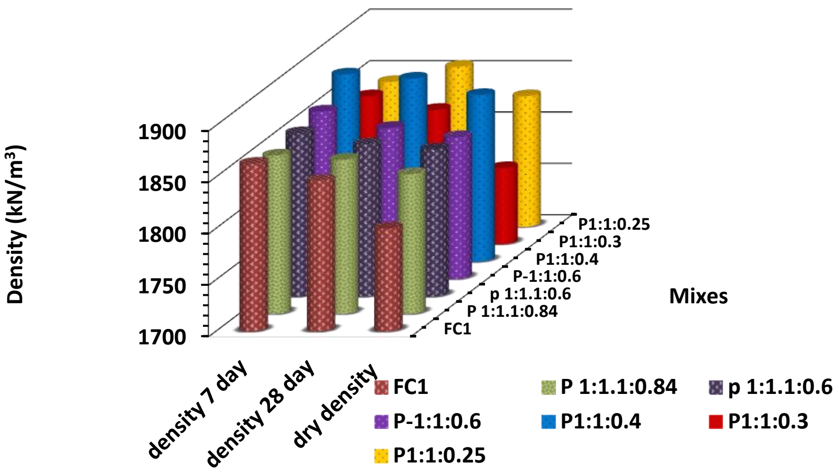

Figure .12 Results of Densities for Porcelanite

4.3 Compressive strength

The result of compressive strength at age 7 and 28 days with various fly ash replacement percentages showed increase in compressive strength with increasing percentage of replacement fly ash .the increasing approximate of (27,39,39,17,8)% for mixtures (Fsh-70, Fsh -50, Fsh-45, Fsh-30, Fsh -25) respectively relative to control mix. Thus, the optimum of the percentage of replacement was (45-50) % to give maximum compressive strength, as shown in Fig.13. In mixture with lightweight coarse aggregate the decrease in the compressive strength by increasing the percentage of additional lightweight aggregate due to weak and dense particles.

The presence of lightweight aggregate in foamed concrete has been observed to benefit from failure, the failure cracks of the specimen have aggregate small width due to inaction between contained materials.

This type of failure is attributed to the adhesion characteristics of cement and aggregate particle, adhesions strength at the interface bounder cement stone and particle and adhesion strength at the interface boundary of cement and aggregate particle adhesion Strength at the interface boundary.

The form of failure largely depends on the bond between the mortar and aggregates. The type of aggregates had an obvious effect on the compressive strength. The percentage of increase in compressive strength of the mixture (LE-4 1:1:.4) compared with Porcelanite with the same percentage (P-1:1:0.4) is about 26%.Thus, type of aggregate shows a significant effect on compressive strength, Leca aggregate was better than porcelanite in strength which is more stiffness as shown Fig (14-15). In general, after failure stage shows the cube with aggregate had small cracks and more stiff from fly ash. The ratio of cement to sand has large effect on compressive strength, the optimum ratio of this stud was 1:1 because increasing percentage of cement led to increasing in compressive. The ratio of sand to the amount of binder has affected the strength of foamed concrete.

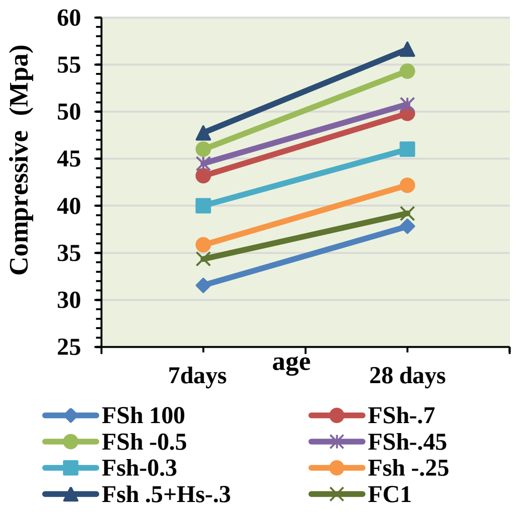

Figure .13 Results of Compressive For Flyash

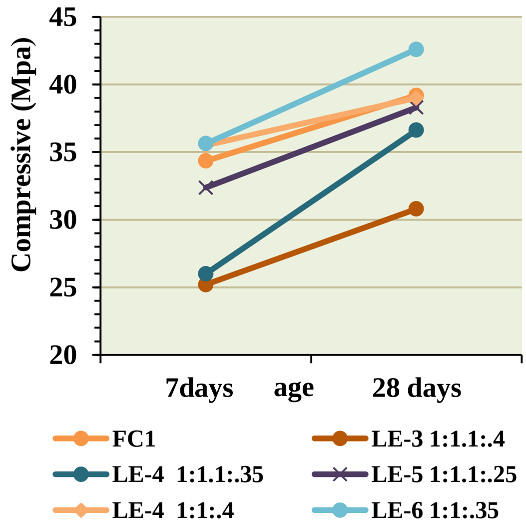

Figure .14 Results of Compressive For LECA

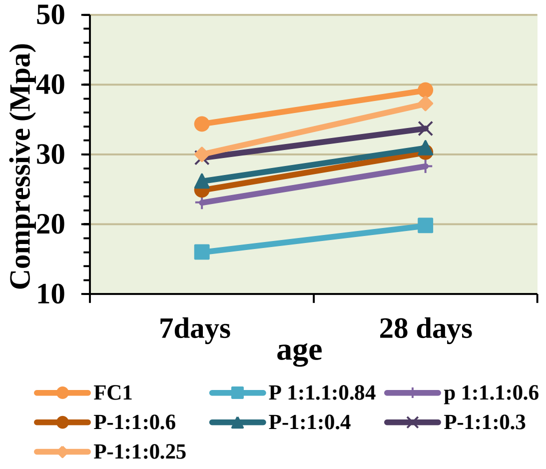

Figure.15 Results of Compressive For Porcelanite

4.4 Modules of elasticity

The ratio of the modulus of elasticity increased with increasing compressive strength and density. The percentage of increased modulus of elasticity for mixtures with fly ash approximate of (8, 32, 17, 22, 9) % for (Fsh-70, Fsh -50, Fsh-45, Fsh-30, Fsh -.25) respectively compared with foam control .The mix with replacement 100 % fly ash show decrease in modulus of elasticity about (11%) compared with control mix as shown Fig.18. The optimum percentage of replacement is (50%) from sand. The modules of elasticity were calculated using ACI213R, 523R equation [31],[1].

It can be seen that there is a clear difference in the value of modulus of elasticity between experimental and theoretical. This might be attributed to fact that at time of setting this equation, the materials were different or they had been developed, in addition to the pressure of the different ingredients in the mix such as, silica fume, superplasticizer steel fiber, as well as foaming agent and lightweight aggregate .these material, might not take into consideration for the ACI equation as shown Fig (16-18) explain the results of modules of elasticity for mixtures with lightweight coarse aggregate.

The ratio of the modulus was observed to increase with increasing compressive strength and density, thus, providing the lowest ratio for compressive to lightweight aggregate for the mixtures due to the increased porosity the proportion of air void .The results showed a good improvement rate for the development of the additional of the aggregate from the control mix.

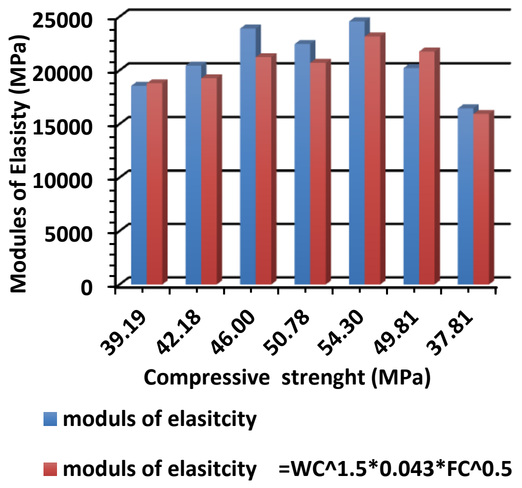

Figure .16 Results of modules of elasticity for fly ash

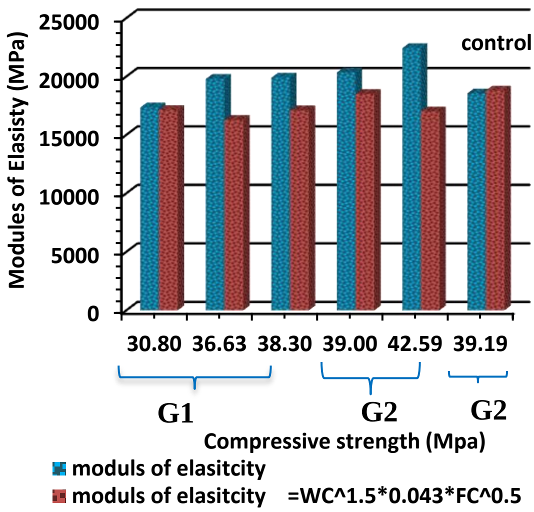

Figure 17.Resulte of modules of elasticity for LECA

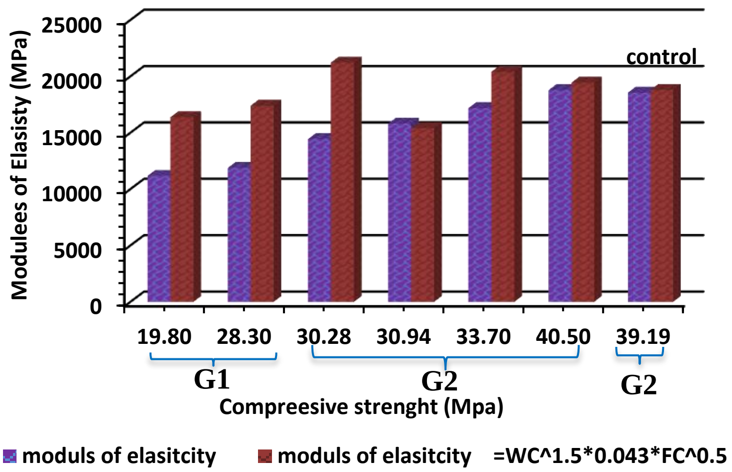

Figure .18. Results of modules of elasticity for porcelanite

5. Conclusions

1. The flowability decreased with increasing percentage of replacement fly ash from sand.
2. The workability of mixtures was increased with the addition of lightweight aggregates.
2. The density is reduced by increasing the foam ratio and the additional percentage of lightweight aggregates. Increase percentage of fly ash decrease density and reduced foam mortar
3. The percentage of replacement fly ash (50%) show increase compressive strength approximate of (39%).Thus compressive strength increase by increasing percentage of fly ash.
5. The optimum percent replacement for fly ash is 50% from sand.

6. Compression strength decreases with the increase of additional lightweight aggregate, thereby reducing compressive strength for Porcelanite and Leca by (5-49)% and reduce in compressive for Leca from (2-50)%.
8. The percent of 50% of fly ash give the maximum value of modulus of elasticity. It is 23.1 GPa at 28 days.
9.The modules of elasticity have been adopted to increase the compressive strength of all mixtures.
10. The ratio of sand to cement effect of compressive strength and modules of elasticity .the ratio of sand to cement 1:1 show optimum increasing for compression strength.
11. The results shows that the fly ash is good to used in structural lightweight foamed concrete.
12. Type of concrete has large effect on compression strength and modulus of elasticity
13. There are approximations in the results of the experimental and ACI code equation

4. References

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