ISSN: 1813-162X
Tikrit Journal of Engineering Sciences
available online at: http://www.tj-es.com

Proportioning of Lightweight Concrete by the Inclusions of Expanded Polystyrene Beads (EPS) and Foam Agent

Eethar Thanon Dawood[1] , Ali Jihad Hamad[2]
[1,2] Building and Construction Engineering Department,Technical College, Mosul, Iraq

Abstract

This paper illustrates the performance of lightweight concrete using various amounts of expanded polystyrene beads (EPS) and different amounts of foam agent to produce lightweight concrete. The objective of this paper is to produce lightweight concrete with good workability and strength, by different mix proportion of foam agent (0.4, 0.6, 0.8, 1, 1.2 kg/m^3) and varying water cement ratio (w/c) depending on the flow. Besides, various proportions using different percentages of EPS in order of volume fractions are used. The flow range used in the study is 110-130%. Each mix proportion is tested for compressive strength, modulus of rupture, density and voids ratio. The results gives acceptable ranges of strength for lightweight concrete produced by the inclusions of EPS beads and foam concrete. Therefore, the lightweight concrete produced in this work can be used for structural applications like multistory building frames, floors, bridges and prestressed or precast elements.

Keywords: Expanded Polystyrene Beads (EPS); Foam agent; Foam concrete; Lightweight concrete.

انتاج خرسانة خفيفة الوزن باستخدام الفلين او عامل الرغوة

الخلاصة

يهدف هذا البحث لإنتاج خرسانة خفيفة الوزن باستخدام كميات مختلفة من الفلين وكذلك من عامل الرغوة. لذلك فقد تم استخدام نسب مختلفة من عامل الرغوة كانت بمقدار 0.4 و 0.6 و 0.8 و 1.0 و 1.2 كغم /م^3 مع استخدام نسب متغيرة من الماء/السمنت بالاعتماد على مقدار الانسياب للخرسانة. تم استخدام نسب مختلفة من الفلين كنسبة حجمية لإنتاج خلطات خرسانية خفيفة الوزن. مقدار الانسياب التصميمي للخرسانة هو 110-130%. وتم اختبار الخلطات في مقاومة الانضغاط ومقاومة الانحناء والكثافة ونسبة الفراغات. اوضحت النتائج بان استخدام الفلين او عامل الرغوة يمكن من الحصول على خرسانة خفيفة الوزن مع الحفاظ على مستويات مقاومة الانضغاط والانحناء بمديات مناسبة لاستخدامها كخرسانة انشائية مثل الابنية الهيكلية المتعددة الطوابق والارضيات والجسور والخرسانة المسبقة الصب او الجهد.

الكلمات الدالة: حبيبات الفلين، العامل الرغوي، الخرسانة الرغوية، الخرسانة الخفيفة الوزن.

Introduction

Lightweight concretes have an oven-dry density range about 300 to not excess of 2000 kg/m^3, with compressive strength for cube about 1 to more than 60 MPa, thermal conductivities of 0.2 to 1.0 W/mK. These values can be compared with those for normal weight concrete of approximately 2100–2500 kg/m^3, 15 to greater than 100 MPa and 1.6–1.9 W/mK[1]. The comparison between lightweight concrete with ordinary concrete shows that lightweight concrete demonstrates some excellent features such as lower density, higher specific strength and better thermal insulation. Lightweight concrete has been a likely modern construction material that can be used for construction applications of high rise buildings, floating marine platforms, larger-sized and long-span concrete structures[2-5]. The types of lightweight concrete can be classified according to method of production. These types according to Neville and Brooks (2010)[6], are produced as follows :

a- Using lightweight aggregate of low specific gravity in place of normal weight aggregate, specific gravity for lightweight aggregate is lower than 2.6. This type of concrete is well-known as lightweight aggregate concrete.

b- Inducing bubble voids within the concrete or mortar mass. This type of concrete is known as aerated, cellular, foamed, or gas concrete.

c- Elimination the fine aggregate from the mix so the coarse aggregate of ordinary weight is generally used. This concrete is known as no-fines concrete.

The lightweight concrete having bulk density lower than 1950 Kg/m^3 and compressive strength more than 17MPa, such concrete is known as structural lightweight concrete. The structural lightweight concrete is 25% lighter than normal-weight concrete with a compressive strength up to 60MPa[7].

Lightweight aggregates can be used to produce lightweight concrete when the weight of aggregates lower than 1120kg/m^3[8]. Lightweight aggregates have many sources: natural materials such as shales, clays, and slates or artificial materials (by products) such as iron blast furnace slag[9,10], properties of lightweight aggregate concrete depend on type of lightweight aggregate in the concrete[10], structural lightweight aggregates can produce concretes with compressive strengths in excess of 35MPa, a limited number of lightweight aggregates can be used in concretes that develop cylinder strengths from 48 to more than 69MPa[11]. Lightweight aggregate are broadly classified into two types: natural (pumice, diatomite, volcanic cinders, etc.) and artificial (perlite, clay, sintered fly ash, expanded shale, etc.). Expanded polystyrene (EPS) is a type of artificial lightweight aggregate with the density of only (10–30)kg/m^3[12]. Expanded polystyrene (EPS) is a kind of stable foam with low density, consisting of discrete air voids in a polymer matrix. The polystyrene beads can be easily incorporated in mortar or concrete to produce lightweight concrete or cement mortar, with a wide range of densities.

Aerated concrete is produced by introducing or generating bubbles voids within the concrete (cement matrix), the voids or cell structure having a homogeneous distribution in cement matrix when formed of voids inside the fresh cement mixture , density range from (300 to 1600)kg/m^3[9,13]. Aerated concrete is known as foamed concrete, foamed concrete is classified in two types according to method producing i. pre-foaming method include preformed foamed (foam agent with water) and mixed with cement slurry (cement paste or mortar), ii. mixing foaming method is mixed of foam agent with cement slurry, foam will produced voids inside the concrete[14-16]. Density of foam concrete about (400 to 1600 kg/m^3) depending on proportion of foam agent and water, foam concrete can be used for structural application, partition, insulation and filling grades[14]. The range of Water-cement ratio (*w/c*) is from (0.4 to 1.25)[17]. There are two types of preformed foam wet or dry foam. Wet foam is produced by using mesh (bubbles of 2-5 mm in size) and then spraying a solution of foaming agent over a fine mesh. Dry foam is produced by forcing the foaming agent solution through a series of high-density restrictions and simultaneously forcing compressed air into the mixing chamber. Dry foam is extremely stable compare with wet foam (less stable) and has a size smaller than 1 mm. This makes it suitable for easier application in base materials required in producing pump able foamed concrete[18]. Compressive strength for foam concrete decreases exponentially with a reduction in density of foam concrete[19]. The affecting factors on strength of cellular concrete are: specimen size and shape, the method of pore formation, direction of loading, age, water content, characteristics of ingredients used and the method of curing[20].

Therefore, this paper is aimed to investigate the use of EPS and foam agents with various percentages for the production of lightweight concrete and test the properties of such concrete.

Materials and mix proportion

Materials

The materials used in the present work are: cement, sand, water, and foam agent or expanded polystyrene beads (EPS). These materials are blended with different mix proportion to obtain structural lightweight concrete with good workability and strength.

Ordinary Portland cement (OPC) type (I) from Badoosh manufacture of Iraq was used in concrete mixtures. The physical characteristics of ordinary Portland cement is showed in Table (1) and conformed to IQS: 5/1984[21]**.** Whereas the chemical compositions for the cement are shown in Table (2) and they are conformed to ASTM C150[22]. The fine aggregate was natural river sand; the grading limit is according to ASTM C33[23] and shown in Table (3). The specific gravity and fineness modulus are 2.63 and 2.69 respectively. The foam agent (NEOPOR) (leyco Chem LEYDE GmbH Germany) is an organic material, which has no chemical reaction but serves solely as wrapping material for the air to be encaspsuled in the concrete. The foaming agent has to be diluted in 40 parts of water before using it. The expanded polystyrene beads are obtained as raw materials from the commercial sources and these beads are small in diameter and hard beads. The beads are modified by boiling water to conform the expanded polystyrene beads. Expanded polystyrene beads have density equal to 13kg/m^3 and specific gravity 0.02.

Mix proportions

The proportion of the mixture with foam or EPS was 1:2.25 (cement:sand). Firstly, cement and sand were mixed according to the mix proportion. Secondly, water was added to prepare mortar. Thirdly, foam agent was diluted in 40 parts of water according to manufacturer (leyco Chem LEYDE GmbH Germany), this water is considered as a part of total water of the mix. Water cement ratio (w/c) was determined depending on flow of the mix (flow range 110-130%). Lastly, the foam was added to the mortar and the flow of the batch was measured by using flow table according to ASTM C 1437[24] and ASTM C230[25]. The fresh density for all mixes were measured and recorded as shown in Table (4). On the other hand, for the mixes with expanded polystyrene beads (EPS), the addition of these beads were added to the mortar 1:2.25 and mixed. The proportions of EPS were calculated and also the flow and fresh density are shown in Tables (4) and (5).

Table 1. Physical characteristics of ordinary Portland cement

Test	Result	IQS : 5/1984
Consistency	0.25	0.24-0.32
Initial setting time (minute)	229	Min. 45 minute
Final setting time (minute)	285	Max. 600 minute
Fineness (%)	5	Max. 10%

Table (2) Chemical properties of ordinary Portland cement

Constituent	Component of OPC (%)	Limits of IQS : 5/1984
SiO_2	21.31	…
Al_2O_3	5.89	…
Fe_2O_3	2.67	…
CaO	62.2	…
MgO	3.62	≤ 5%
SO_3	2.6	≤ 2.8%
Loss of ignition	1.59	≤ 4%
Insoluble residue	0.24	≤ 0.75%
Free CaO	1.74	…
L.S.F.	0.8818	…
C_3S	33.37	…
C_2S	35.92	…
C_3A	11.09	…
C_4AF	8.12	…

Table 3. Grading of fine aggregates

Sieve No. (mm)	Passing (%)	Limits of ASTM C 33
No.4 (4.75)	100	95-100
No.8 (2.36)	80.96	80-100
No.16 (1.18)	66.33	50-85
No.30 (0.6)	51.5	25-60
No.60 (0.3)	24.65	5-30
No.100 (0.15)	7.26	0-10

Table 4. Mix proportions

Mix No.	Mix proportion	W/C	Cement kg/m³	Sand kg/m³	Water kg/m³	EPS (%) by volume of concrete	Foam agent kg/m³	Theoretical density kg/m³	Flow (%)
C0	(1 : 2.25) (cement : sand)	0.47	566.07	1273.65	266.05	—	—	2105.77	110
C1		0.48	526.47	1184.56	252.70	13.00	—	1963.75	110
C2		0.46	513.01	1154.28	235.98	16.25	—	1903.29	110
C3		0.45	476.11	1071.26	214.25	22.75	—	1761.63	110
C4		0.44	438.75	987.20	193.05	29.25	—	1619.02	110
C5		0.46	393.56	885.52	181.04	35.75	—	1460.12	110
C6		0.47	351.59	791.09	165.25	42.25	—	1307.93	110
C7		0.44	551.93	1241.86	242.85	—	0.4	2036.64	110
C8		0.43	533.54	1200.46	229.42	—	0.6	1963.42	110
C9		0.42	532.43	1197.97	223.62	—	1	1954.02	110
C10		0.42	492.18	1107.40	206.71	—	1.2	1879.34	110
C11		0.49	452.33	1017.74	221.64	—	1	1691.71	130
C12		0.53	494.56	1112.77	262.12	—	0.6	1869.45	125
C13		0.46	521.77	1173.98	240.01	—	0.8	1935.76	120

Table 5. Hardened concrete properties

Mix No.	Fresh density kg/m³	Dry density kg/m³	Compressive strength MPa		Modulus of rupture MPa		Voids (%)
			7 days	28 day	7 days	28 day	
C0	2460.00	2376.00	38.56	47.98	6.90	8.54	7.00
C1	2019.84	1936.00	18.86	29.31	4.89	5.62	14.10
C2	1930.12	1860.50	15.44	28.50	4.90	5.36	17.40
C3	1839.64	1791.08	16.87	21.89	3.46	4.05	23.20
C4	1768.00	1726.00	14.47	18.29	2.49	3.20	31.50
C5	1694.15	1638.43	13.70	16.13	2.30	2.83	36.50
C6	1589.23	1498.18	11.25	14.50	2.12	2.56	43.16
C7	2056.70	1920.12	19.52	28.79	4.25	5.14	11.00
C8	2000.00	1870.22	22.76	31.34	4.51	5.50	14.50
C9	1953.04	1830.45	23.82	34.02	4.26	5.36	15.21
C10	1855.09	1725.90	12.45	16.10	2.30	2.78	21.62
C11	1750.00	1690.84	14.00	20.50	3.10	4.15	24.30
C12	1938.90	1894.53	10.79	19.00	2.74	3.41	15.87
C13	1970.31	1829.08	17.63	25.95	3.86	4.69	14.82

Experimental Work

The moulds of 50 mm cubes were used for testing the compressive strength of lightweight concrete according to ASTM C109[26]. The average of three cubes is used to determine the compressive strength for each age of test. Besides, the prismatic moulds of (40×40×160) mm were used to determine the flexural strength according to ASTM C348[27]. The average of three prisms was used to determine the flexural strength. The density and voids were determined using (100) mm cubes according to ASTM C642[28]. Foam produced by using a mixer, which forming the foam according to the pre-foaming method, adding the preformed foam to a base mix (cement, sand, and water). In expanded polystyrene beads case, the EPS beads should be mixed well in order to distribute the beads in all mix and to prevent them from being as lumps in concrete mix.

Results and Discussion

Flowability

The results of the flow for each mix are shown in Table (4). The recorded range of flow is between (110–130)%. The flow depends on the water cement ratio, whereas the water cement ratio is affected by EPS beads proportions as given in Figure (1). It can be seen from this figure that the increase of expanded polystyrene beads would reduce the flowability of lightweight concrete and more water in mix is required. The mix C4 has given the optimum flow 110% with w/c equal to 0.44 and 29.25% of EPS beads. This mix gives acceptable values of compressive strength of 18.29 MPa and flexural strength of 3.2MPa. On the other hand, for foam concrete the flowability depends on the water cement ratio and also foam agent percentage. Too wet mortar may lead to unstable foam, whereas too dry mortar would make the foam unable to blend with the mortar[29]. The mix C11 gives the highest value of flowability 130%, this is may be due to the suitable amount of foam and the high w/c ratio equal to 0.49, and thus the foam concrete is very sensitive and affected by water amount in the mixture[6].

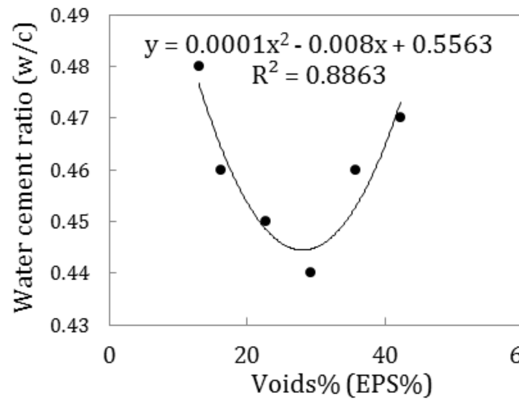

Fig. 1. Effect of EPS beads percentage on water cement ratio, (flow 110%)

Fresh and Dry Density

The voids in the concrete containing EPS beads related to the EPS volume percentage in the mix. Thus, the increase of EPS beads tends to reduce the fresh density of concrete as well as, its effect on dry density as shown in Table (5) and Figure (2). It can be seen from this Figure that the increase in the EPS beads percentage would result in significant reduction in dry density of lightweight concrete.

For foam concrete, the dry density decreased with the increasing foam volume (voids). The foam volume depends on the amount of foam agent in the mix and water cement ratio, continuously, the water cement ratio would also form the voids within concrete[6]. Figure (3) shows the relationship between foam volume and dry density. The dry density is reduced with foam volume increased, this may be due to the increase of the interior voids in concrete. However, the density of lightweight concrete is reduced with the increase of voids that represent EPS beads or foam volume.

Compressive Strength

Table (5) shows the results of compressive strength for specimens at ages of 7 and 28 day after water curing. It can be seen that C0 (reference mix) has a compressive strength of 47.98MPa. Whereas, the mixes C1-C6 for concrete which contain expanded polystyrene beads exhibit significant decrease in compressive strength as the amount of EPS beads increase. This can be attributed to the fact that the compressive strength of concrete might be affected by voids ratio and w/c ratio of the mix. Thus, the increase in voids and w/c ratio cause a reduction in the compressive strength of the lightweight concrete[6,30]. The water cement ratio is changed for each mix to maintain 110% flow. The mix C1 gives highest compressive strength 29.31MPa due to the least percentage of EPS beads 13%, in spite of the highest water cement ratio 0.48. On other hand, the increase of EPS beads in the mix C2 decreases the compressive strength of lightweight concrete to 28.5MPa. This slight decrease may be attributed to the fact that w/c for the mix C2 is 0.46 whereas the w/c for mix C1 is 0.48. Figure (4) shows the relationship between EPS beads and compressive strength of lightweight concrete. However, from the mentioned figure, it can be seen that the increase of EPS decreases significantly the compressive strength. Furthermore, dry density has reduced with the increase of the EPS beads (voids) but the decrease in dry density will reduce the compressive strength as shown in Figure (5). The comparison between C6 and C0 shows that the reduction of compressive strength of such concrete was about 69.77% by the inclusion of EPS beads in order of 42.25%.

On the other hand, the results of compressive strength for the lightweight concrete mixes containing foam agent (mixes C7-C13) show that the voids exists in concrete depends on the amount of foam agent in the mix and also the water cement ratio in the mix[6]. The Compressive strength of the foam concrete has reduced as the foam volume increased. Figure (6) shows the relationship between compressive strength and foam volume. Also the compressive strength is reduced with the reduction of dry density of lightweight concrete. This can be attributed to the effect of foam volume (voids) that induced in such concrete as shown in Figure (7). From the previous results, it can be seen that mix C9 gives acceptable values of compressive strength 34.02MPa, dry density 1830.45 kg/m^3 and flow 110% as given in Table (5).

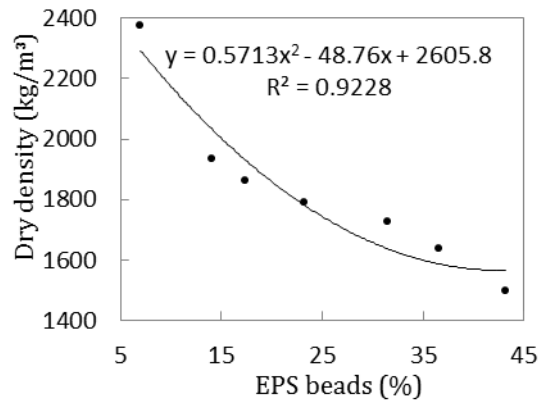

Fig. 2. Relationship between EPS beads and dry density

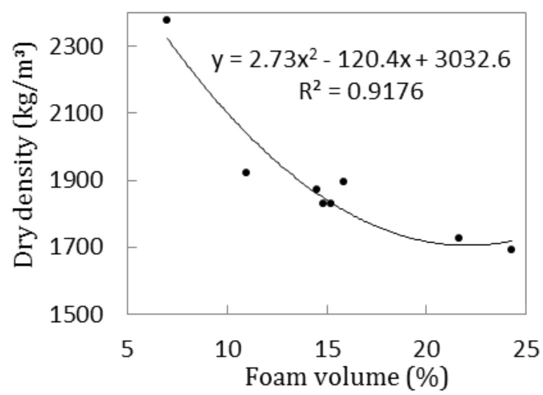

Fig. 3. Relationship between foam volume and dry density

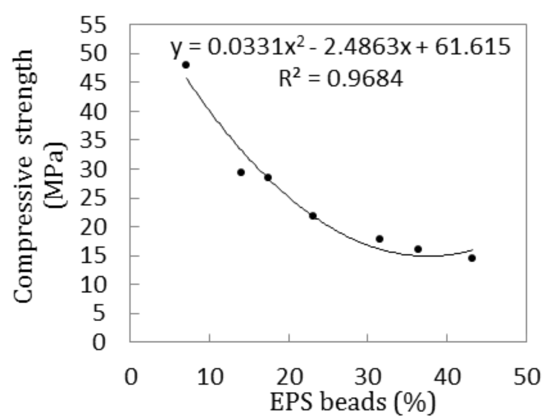

Fig. 4. The relationship between EPS with compressive strength of concrete

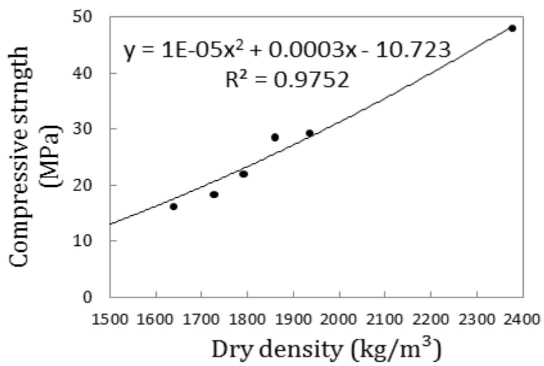

Fig. 5. The relationship between the compressive strength and dry density for concrete containing EPS beads

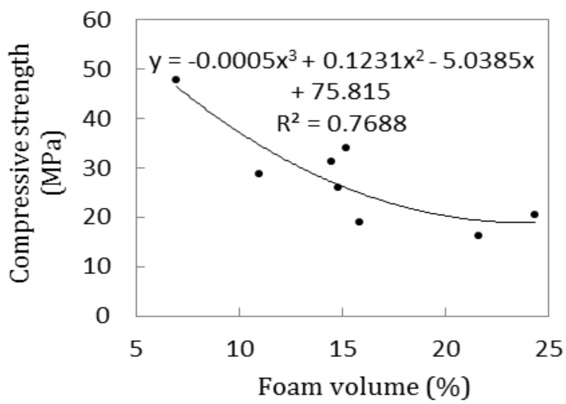

Fig. 6. The relationship between foam volume and the compressive strength of concrete

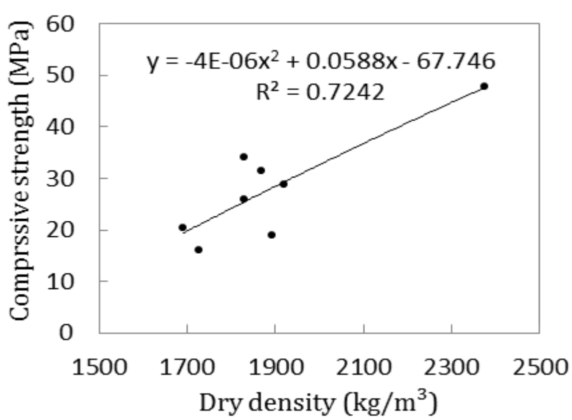

Fig. 7. The relationship between the compressive strength and dry density for concrete contain foam agent

Modulus of Rupture

Table (5) shows the results of modulus of rupture for lightweight concrete containing EPS beads or foam agent. The modulus of rupture for concrete containing EPS beads is reduced with the increase of EPS beads volume. Concrete Mix C1 shows good modulus of rupture 5.62 MPa due to low volume fractions of EPS beads. However, modulus of rupture has reduced gradually with the increase of EPS beads proportion as shown in Figure (8). The least value of modulus of rupture is obtained with mix C6 2.56 MPa. For lightweight concrete forming from foam agent, the modulus of rupture is affected by water cement ratio and amount of foam agent[31]. Increasing the amount of foam agent would increase the foam volume (voids) and subsequently reduce the flexural strength as shown in Figure (9).

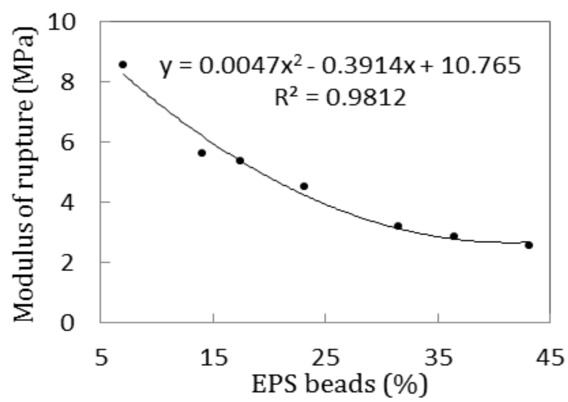

Fig. 8. The relationship between of EPS beads and modulus of rupture

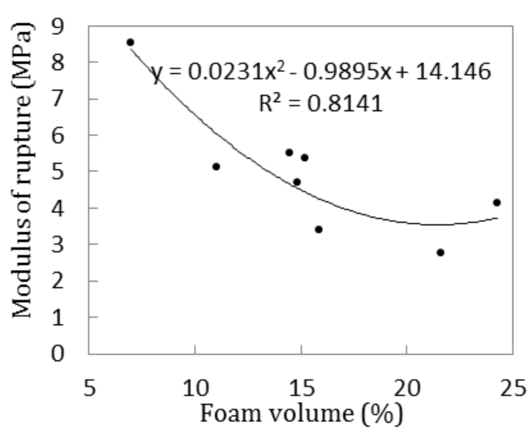

Fig. 9. The relationship between of foam volume and modulus of rupture

Conclusions

This paper shows proportioning of lightweight concrete having acceptable workability, density, compressive strength and modulus of rupture by using EPS beads or foam agent. Some conclusions can be drawn as follows:

1-The density of lightweight concrete is reduced with the increase of the voids resulted from EPS beads or foam volume. Thus, the density of lightweight concrete was 1498 kg/m^3 by inclusion of 43.16% EPS. Whereas the density of foamed concrete was 1690.84kg/m^3 by the inclusion of 1kg/m^3 foam agent.

2-For the lightweight concrete with EPS beads, the use of 31.5% of EPS exhibits the best performance in terms of density, compressive strength and modulus of rupture. The values for them are: 1726 kg/m^3, 18.29 MPa and 3.2 MPa, respectively.

3-For lightweight concrete using foam agent, the use of 1 kg/m^3 of foam agent is found to induce about 15.21% of voids in the lightweight concrete mix and thus the best performance for density, compressive strength and modulus of rupture are: 1830kg/m^3, 34.02MPa and 5.36MPa, respectively.

References

1- Owens, P., Newman, J. and Choo B. S., "Advanced Concrete Technology Processes", Elsevier Ltd, 2003.

2- Alshihri, M. M., Azmy, A. M. and El-Bisy, M. S., "Neural Networks for Predicting Compressive Strength of Structural Light Weight Concrete", Construct Building Material, Vol. 23, No. 6, pp. 2214-2219, 2009.

3- Babu, D. S., Babu K. G. and Wee T. H., "Effect of Polystyrene Aggregate Size on Strength and Moisture Migration Characteristics of Lightweight Concrete", Cement and Concrete Composite, Vol. 28, No. 6, pp. 520–527, 2006.

4- Chen, B. and Liu, J., "Contribution of Hybrid Fibers on the Properties of the High Strength Lightweight Concrete having Good Workability", Cement & Concrete Research, Vol. 35, No. 5, pp. 913–917, 2005.

5- Chia, K. S., Zhang M .H., "Water Permeability and Chloride Penetrability of High Strength Lightweight Aggregate Concrete", Cement and Concrete Research, Vol. 32, No. 4, pp. 639–645, 2002.

6- Neville, A. M. and Brooks, J. J., "Concrete Technology", Second edition, Prentice Hall, Pearson Education, pp. 339-340, 2010.

7- Guo, Y. S., Kimura, K., Li, M. W., Ding, J. T. and Huang, M. J., "Properties of High Performance Lightweight Aggregate Concrete", International Symposium on Structural Lightweight Aggregate Concrete, No. 2, pp. 548-561, 2000.

8- Mehta, P. K., and Monteiro, P. J. M., "Concrete: Microstructure, Properties and Materials", Third edition, New York: McGraw-Hill, 2006.

9- Neville, A. M., "Properties of Concrete", Fourth and Final Edition, Prentice Hall, pp.711-713, 2000.

10- ACI 213R-87, "Guide for Structural Lightweight Aggregate Concrete", Detroit, Michigan, 1999.

11- Walraven, J., "Self-Compacting Concrete in the Netherlands", Proceedings of the First North American Conference on the Design and use of Self-consolidating Concrete, Evanston, USA، , pp. 355-360, 2002.

12- Miled, K., Roy R. L., Sab, K. and Boulay, C., "Compressive Behavior of an Idealized EPS Lightweight Concrete: Size Effects and Failure Mode". Mechanics of Materials, Vol. 36, No. 11, pp. 1031–1046, 2004.

13- Fouad H. F., Lamond, J. F. and Pielert, J. H., "Significance of Tests and Properties of Concrete and Concrete-Making Materials, stp 169d , ASTM International, 2006.

14- Ramamurthy, K., Kunhanandan Nambiar, E. K. and Ranjani, G. I. S., "A Classification of Studies on Properties of Foam Concrete", Cement and Concrete Composites, Vol. 31**,** pp. 388-396, 2009.

15- BYUN, K. J., SONG, H. W. and PARK, S. S., "Development of Structural Lightweight Foamed Concrete using Polymer Foam Agent. ICPIC-98, 1998.

16- Short, A. and Kinniburgh, W., "Lightweight Concrete", 3rd Ed., Applied Science Publishers Ltd., London, pp. 1-14, 1978.

17- Zulkarnain, F. and Ramli, M., "Performance of foamed concrete mix design with silica fume for general housing

construction", European Journal of Technology and Advanced Engineering Research, No. 2, pp. 18-28, 2011.
18- Aldridge, D., "Introduction to Foamed Concrete What, Why, and How?", In: Dhir RK, Newlands MD, McCarthy A, Editors. Thomas Telford, pp. 1-14, 2005.
19- Kearsley EP. "The Use of Foamed Concrete for Affordable Development in Third World Countries", In: Dhir RK, McCarthy MJ, Editors. Appropriate Concrete Technology. London: E & FN Spon, pp. 233-243, 1996.
20- Valore R C. "Cellular Concrete Part 2 Physical Properties", ACI J 50:817–36, 1954.
21- IQS No: 5, 1984, "Characteristics of OPC", Central Agency for Standardization and Quality Control, Iraq.
22- ASTM C 150, "Standard Specification for Portland Cement", Annual Book of ASTM, standards, Vol. 04.01, 2002.
23- ASTM C 33, "Standard Specification for Concrete Aggregates", Annual Book of ASTM, Standards, Vol. 04.02, 2002.
24- ASTM C 1437, "Standard Test Method for Flow of Hydraulic Cement Mortar", Annual Book of ASTM, Standards, Vol. 04.01, 2001.
25- ASTM C 230, "Standard Specification for Flow Table for Use in Tests of Hydraulic Cement", Annual Book of ASTM, Standards, Vol. 04.01, 2003.
26- ASTM C 109, "Standard Test Method for Compressive Strength of Hydraulic Cement Mortars (Using 2-in. or [50-mm] Cube Specimens)", Annual Book of ASTM, Standards, Vol. 04.01, 1999.
27- ASTM C 348, "Standard Test Method for Flexural Strength of Hydraulic Cement Mortar", Annual Book of ASTM, Standards, Vol. 04.01, 2002.
28- ASTM C 642, "Standard Test Method for Density, Absorption, and Voids in Hardened Concrete", Annual Book of ASTM, Standards, Vol. 04.02, 1997.
29- Barnes, R. A., "Foamed Concrete: Application and Specification", Excellence in Concrete Construction through Innovation – Limbachiya & Kew (eds), Taylor & Francis Group, London, 2009.
30- Abolfazl, S., Kamal, R., Saber P., and Loghman, R., "The Effect of Water-Cement Ratio in Compressive and Abrasion Strength of the Nano Silica Concretes", World Applied Sciences Journal, Vol. 17, No. 4, pp. 540-545, 2012.
31- Mydin, M. A. O. and Soleimanzadeh, S., "Effect of Polypropylene Fiber Content on Flexural Strength of Lightweight Foamed Concrete at Ambient and Elevated Temperatures", Advances in Applied Science Research, Vol. 3, No.5, pp. 2837-2846, 2012.