ENGINEERING PARAMETERS OF RECYCLED POLYSTYRENE CONCRETE MIXTURES

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ABSTRACT

The effect of waste polystyrene aggregate (which used for packing of electrical devices and food packing) on concrete density, water absorption, compressive strength and thermal conductivity was investigated.

Deferent concrete mixtures were made by replacing the sand content by polystyrene aggregate with different volumes (namely, 0%, 5%, 10%, 15%, 30%, 70% and 100%) in concrete with three cement content (300, 450 and 600 kg/m^3).

The density, water absorption and compressive strength of polystyrene concrete decreased with the increase of polystyrene aggregate.

Results showed that the use of polystyrene aggregate in in concrete mixtures caused an increase in water absorption from 1.9% to 9.5% at different polystyrene aggregate ratio.

The compressive strength reduced by ratio by 75% at polystyrene aggregate replacement ratio100%.

Thermal conductivity of polystyrene concrete mixtures decreased from 0.9 to 0.24 W/m.K with the increasing of polystyrene sand ratio up to 100%.

Keywords: *light weight concrete - polystyrene aggregate – compressive strength.*

INTRODUCTION

Waste from the using of polystyrene in the manufacture of electrical and food packaging is a serious environmental hazard. The world is now advocating a reduction in the production of such dangerous substances and re-using them in several fields to reduce its risk.

Lightweight concrete is produced by replacing part or all the aggregate with light aggregates. This concrete has been used in recent construction of buildings, foundations and structures **(Gao et al. 2013).** Several studies have been conducted on polystyrene concrete. Scientific researchers primarily investigate the mechanical properties of polystyrene.

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Perry et al., 1991 reported that the accumulated concrete of polystyrene had a compressive strength ranging from 3MPa to 10MPa.

Babu, et al., 2006 Investigated the effect of addition of mineral additives on the bonding between polystyrene and cement grits and discussed the effect of the shape and size of total polystyrene on the strength of polystyrene concrete.

Kan et al., 2009 Discuss the use of polystyrene waste as a total of concrete and examine its effect on freezing and melting resistance.

Chen et al., 2007 used steel fiber and rubber latex to enhance polystyrene concrete and studied concrete properties such as strength and shrinkage.

The concrete workability of polystyrene has been improved by mechanical properties using ultrafiltration as mentioned **Miled et al., 2011.**

Sadrmomtazi et al., 2013 developed an inference system model to calculate the compressive strength of concrete which mixed with polystyrene foam and rice crust.

Yi X. et al., 2015 verified engineering properties such as density, compressive strength and stress behavior of hollow polystyrene concrete construction, which is done using the optimum mixing ratio of polystyrene.

On the other hand, many researches have been investigated about thermal properties because of the requirements of building energy conservation. **Bonasina et al., 2003,** examined the effect of different temperatures and moisture content on the thermal performance of polystyrene concrete.

Bovard et al. 2007 studied the effect of the size of polystyrene and the mass content on thermal conductivity and the conclusion that the effective differential model was combined with experimental data.

Therefore, the main objective of this study was to study the effect of Portland cement content and the content of the aggregates produced from recycled polystyrene on compressive strength, density, water absorption and thermal conductivity of concrete mixtures.

MATERIALS AND METHODS

The present work was carried out to develop Eco light weight concrete made of recycled polystyrene aggregate with deferent cement **(Table 1).**

Materials:

The used materials for this experiment are locally available, which are illustrated as follow:

1- Portland cement was used as the base binder material.
2- Natural soft aggregates were medium-sized sand.
3- Polystyrene aggregates were manufactured by chopping up the collected waste polystyrene. The virtual density is 40 kg / m^3 and the grain size is 4 mm **(Figure 1).**
4- Additive material (Adibond 65) which was manufactured by CMP company. It complies with US ASTM C 631 standards and technical specifications of the manufacturer **CMBI 2012** and was used to improve the strength and the adhesion between the matrix and polystyrene aggregate.
5- A clean tap water was used during this experiment.

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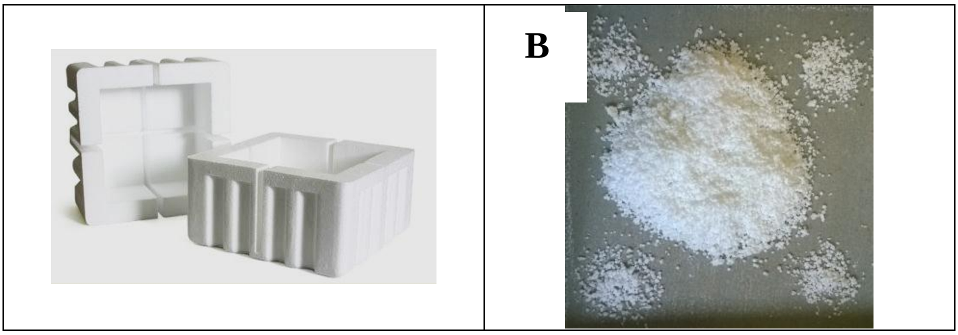

Fig. 1. Recycled Polystyrene before (A) and after (B) chopping

Methodology: The mixtures were divided into three groups (C1, C2 and C3) with cement content of 300, 450 and 600 kg/m^3, respectively. The water/cement(w/c) ratio of 0.45 was used for all concrete mixtures. The polystyrene aggregate was used by 0%, 10%, 20%, 30%, 40%, 50%, 60%, 70%, 80%, 90% and 100% of the volume of the plain sand content **(Figure 2)**. Mixture proportions are calculated as shown in **Table 1** from equation:

$$\frac{C}{\rho_c} + \frac{W}{\rho_w} + \frac{S}{\rho_s} + \frac{P}{\rho_p} + others = 1m^3 \qquad (1)$$

Where:

C – cement mass, t;

W – water mass, t;

S – sand mass, t;

P – polystyrene aggregate mass, t;

$\rho_c, \rho_w, \rho_s, \rho_p$: bulk density of cement, water, sand and polystyrene aggregate.

Methods:

Compressive strength: The compressive strength of the concert mixtures was carried out according to European Standard (DIN EN 196-1). A servo hydraulic testing machine, located in the testing materials lab, Faculty of Engineering, Alexandria University with a maximum capacity of 100 kN was used to apply a constant loading rate test of 140 kg/cm^2/min until failure. A cubic sample dimension with 40 mm was used for testing. Three replicates of compressive strength tests were applied on samples. The compressive strength F_{cs} was calculated as follows:

$$F_{cs} = \frac{L_u}{w^2} \qquad (2)$$

Where:

F_{cs}- Compression stress, MPa,

L_u- Ultimate load, N,

w Sample dimension, cm.

Table 1: Mixture proportions of polystyrene concrete.

Mixture	Cement, kg(cement)/m^3 (concrete)	Sand, kg (Sand)/m^3 (concrete)	Polystyrene aggregate kg (Polystyrene)/m^3 (concrete)	Water kg(water)/m^3 (concrete)
C1 P0	300	1530	0	135
C1P5		1453.50	15.6	
C1 P10		1377	30.6	
C1P15		1300	46.20	
C1 P30		1071	91.8	
C1 P70		459	214.2	
C1 P100		0	306	
C2 P0	450	1295	0	202.5
C2P5		1262.60	12.95	
C2 P10		1165.5	25.9	
C2P15		1100.75	38.85	
C2 P30		906.5	77.7	
C2 P70		388.5	181.3	
C2 P100		0	259	
C3 P0	600	1060	0	270
C3P5		1007	10.55	
C3 P10		954	21.2	
C3P15		901	65	
C3 P30		742	63.6	
C3 P70		318	148.4	
C3 P100		0	212	

P: polystyrene aggregate – sand ratio by volume %.
C1, C2, C3: cement content per cubic meter concrete.

Fig. 2. Experimental samples for recycled polystyrene aggregate – concrete mixtures.

Bulk density: A set of samples with dimensions of 4×4×16 cm was tested to determine hardened concrete mixtures bulk density. Three replicates of each sample were tested after 28 days from removing from the mold. All samples were dried at 105 ± 5ºC until a constant weight was achieved and then was placed in the air to cool down. The bulk density was calculated from:

$$\rho = \frac{W_d}{V} \qquad (3)$$

Where:

ρ - Bulk density of the sample, t/m^3.

W_d- Weight of dry sample, t.

V - Volume of the sample, m^3.

Water absorption: All samples were dried at 110 ºC to achieve a constant weight. Water absorption was determined according to the American Standard Testing Method **ASTM (D-1037)**. The tested samples were then put in water at the normal temprture (25ºC) for 24 hours. Then the samples were hanged to drain the water for 15 minutes. The sample was weighed to the nearest 0.01 gram. The amount of water absorbed after 24 hours of soaking was calculated as follow:

$$W = \left(\frac{W_a - W_d}{W_d}\right) \times 100 \qquad (4)$$

Where:

W - Water absorption ratio, %; W_a- Mass of saturated sample in air, t;

W_d- Sample dry mass, t.

Thermal conductivity: The sample was placed between the hot plate and the cold plate whose temperatures could be controlled automatically.

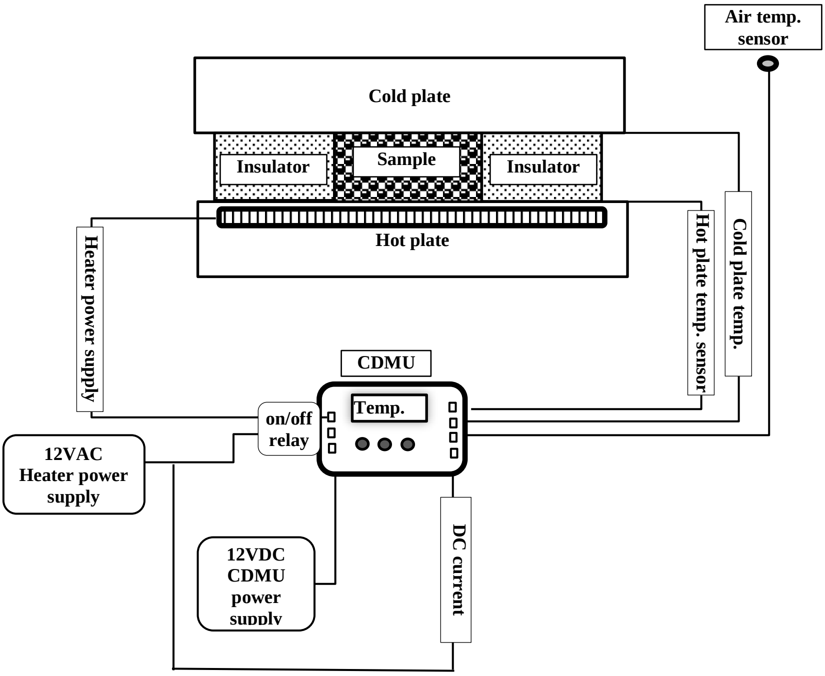

Fig. 3. Schematic of Thermal conductivity measurements experiment setup.

The temperatures at each face of the sample were monitoring by the thermocouples until thermal equilibrium is achieved. The schematic illustration of this standard test method for steady-state thermal transfer mechanism is shown in **Figure 3**

The thermal conductivity was ca from Fourier's law:

$$K = \frac{Q*x}{(T_1 - T_2)*A*t} \quad (5)$$

Where

K- the thermal conductivity, W/m.^{o}K;

Q- the conducted heat across the sample, J;

x -the sample thickness, m;

A- is the metering area of sample, m^2;

t - the time of heat transfer, sec;

T_1- the temperature of hot plate, ^{o}K;

T_2 - the temperature of cold plate, ^{o}K.

RESULTS AND DISCUSSIONS

Compressive Strength:

Figure 4 shows the basic relationship between the percentage of replacement by polystyrene aggregate and the compressive strength for concrete categories C1, C2 and C3. As a result of a volumetric replacement of sand by polystyrene aggregate, compressive strength decreases as the percent of polystyrene aggregate increases. Also, the higher the cement content was in the concrete mixture at the same polystyrene aggregate percentage, the higher the compressive strength was.

For the C3 concrete grade with zero replacement, the compressive strength was 22.2 MPa. At 5% replacement, the compressive strength was 20.5 MPa that represented a reduction of 7.65% compared with the original value. However, for replacement ratios of 10, 15, 30, 70, and 100%, the compressive strength decreased to 22.07%, 37.84%, 56.30%, 67.12% and 72.52%, respectively. For C1, the compressive strength was 16, 14.8, 12, 9.5, 6 and 3.8 MPa for replacements values of 0, 5, 10,15, 30, 70, and 100%, respectively. The drop percentages reflecting those percentages were 7.5, 25, 40.6, 62.5, 75 and 76.25 respectively. In comparing C2 with C1, it was noticed that at 5, 10, 15, 30, 70 and 100%, the differences were 25.6, 29.7, 25, 18.9, 20.6 and 36.8 % respectively. Additionally, it was noticed that concrete grade C2 was slightly better for compressive strength compared to C1.

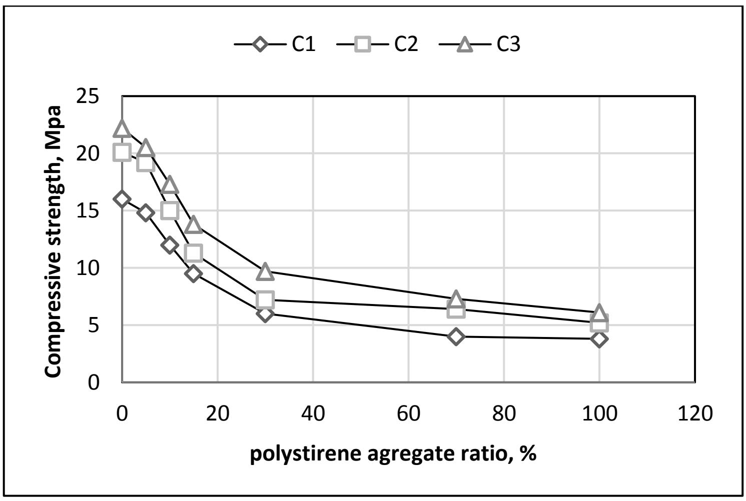

Fig. 4. Relationship between polystyrene aggregate ratio and compressive strength**.**

Figure 5 shows how compressive strength changed with percent of volumetric replacement of sand by waste polystyrene aggregate relative to the specified compressive strength. This happened because as replacement increases, bonding between aggregate particles and cement decrease, and because of the weakness of polystyrene aggregate with comparison to sand.

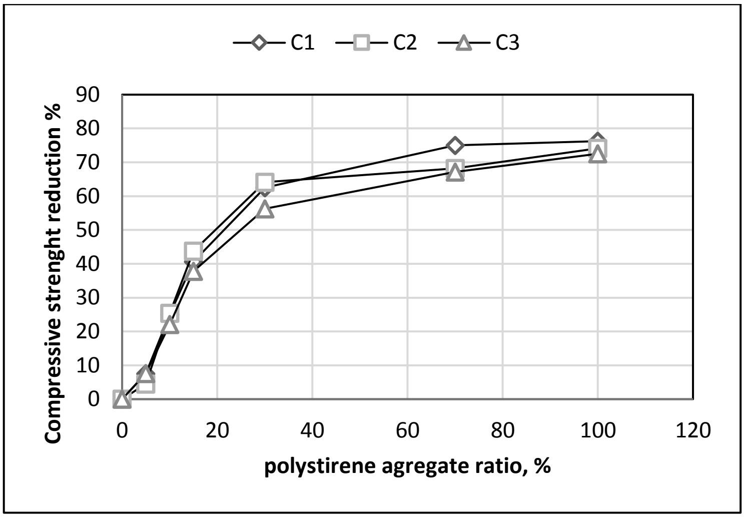

Fig. 5. Relationship between polystyrene aggregate ratio and compressive strength reduction according to mixture without polystyrene aggregate.

Figure 6 shows the incensement percent of compressive strength for both concrete mixtures C2 and C3 relative to concrete mixture C1 at different polystyrene aggregate ratios. A significant improvement in compressive strength values was observed by increasing the cement content in all mixtures up to 70% polystyrene aggregate ratio.

Figure (7) shows the regression analysis between the compressive strength, cement content and polystyrene aggregate to sand ratio of concrete. A strong relationship was obtained as follow:

$$CS=8.767-0.000018\,C^2+0.0029F^2+0.0312C-0.415F \quad (R^2=97.6) \quad (6)$$

Where:

CS = compressive strength, MPa; C = cement content, kg/m^3;

F= polystyrene to sand ratio, % by volume

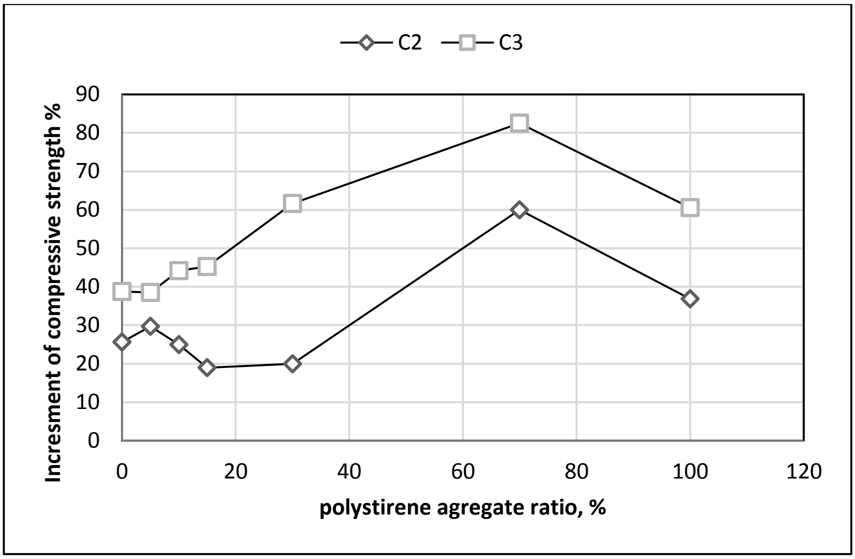

Fig. 6. Relationship between polystyrene aggregate ratio and increasement of compressive strength ratio according to mixture C1.

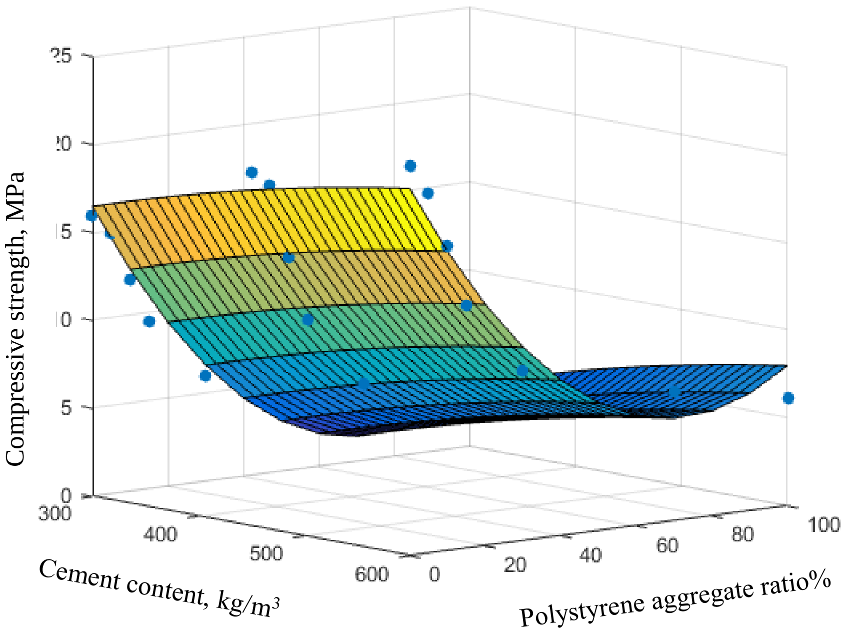

Fig. 7. Regression analysis between the compressive strength, cement content and polystyrene aggregate to sand ratio.

According to The Egyptian Standards (1349-1991) the mixture C3 up to 70 %, the mixture C2 up to 30% and the mixture C1 up to 15% polystyrene content are accepted as carrying brick materials. Also, all the concrete mixtures with polystyrene content above the last ratios was accepted as non-carrying bricks.

Density:

Figure (8) illustrates the relationship between the polystyrene aggregate percentage and concrete density for mixtures C1, C2 and C3. As a result of a volumetric replacement of sand by polystyrene aggregate, concrete density decreases as the percent of polystyrene aggregate increases. Also, the higher the cement content was in the concrete mixture at the same polystyrene aggregate percentage, the higher the concrete density was. The reduction of concrete density was due to replacing the high-density sand with low density polystyrene aggregate. Also, the addition of polystyrene aggregate will cause increment in void and thus lower the density of the concrete.

For the C3 concrete grade density was decreased from 2.2 t/m3 at zero replacement to 2.15, 1.95, 1.87, 1.73, 1.2 and 1.1, for replacement ratios of 10, 15, 30, 70, and 100%, respectively. Also, the density of C1 mixture decreased from 2.08 to 0.7 due to increasing the polystyrene aggregate replacement ratio from zero to 100%. On the other hand, the density of mixture C2 lies between C1 and C3 at all polystyrene aggregate ratio. In theory, the relationship between apparent density and polystyrene volume of lightweight concrete is linear. The experimental results of samples in concrete series C1, C2, and C3 agreed well with the theoretical values.

All the concrete mixtures show polynomial relationship between concrete compressive strength and density as shown in **Figure (9).**

In accordance with the Egyptian standard for cement bricks (1349-1991), the standard density of sand cement is 2 g / cm3. Therefore, to give a clear picture of the amount of shrinkage that will occur due to the use of polystyrene particles as a component of brick making, calculating of the percentage reduction for each mixture of concrete provided in **Figure (10).** Therefore, this reduction in weight can be considered as advantage compared to sand-cement material. The low-density material can reduce the load that is subjected to the ground especially in the construction in weak soil.

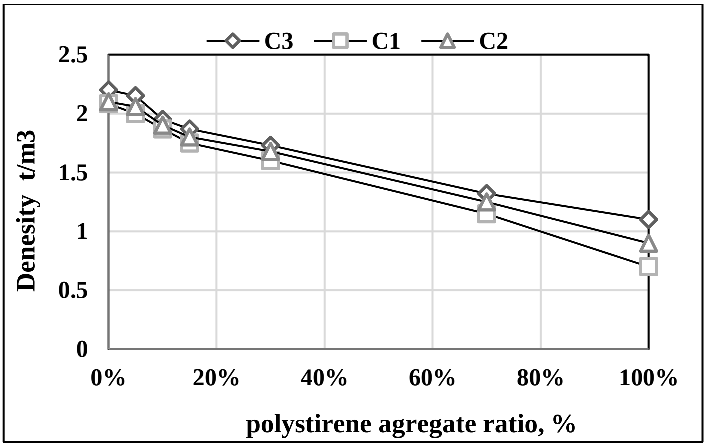

Fig. 8. Relationship between polystyrene aggregate ratio and density at different concrete mixtures.

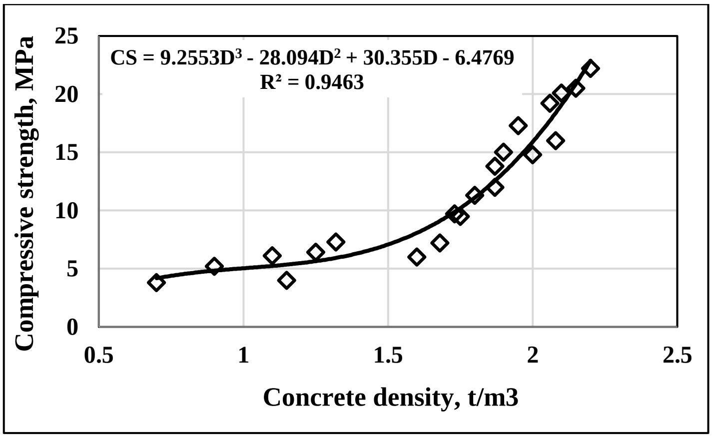

Fig. 9. Relationship between concrete density compressive strength.

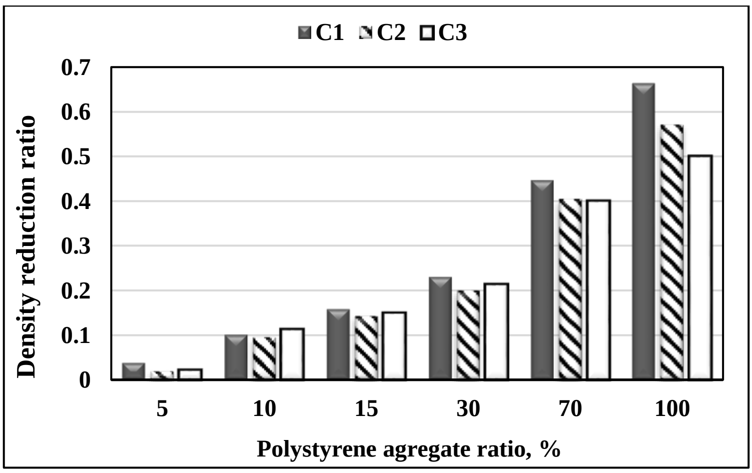

Fig. 10. Reduction percentage of each concrete mixture density.

Figure (11) shows the relationship between the dry density, cement content and polystyrene aggregate to sand ratio of concrete. A strong relationship was obtained as follow:

$$D=1.812+ 0.000557 C- 0.0118 F, \quad (R^2= 93.6) \quad (7)$$

Where:

D = concrete density, t/m^3

C = cement content, t/m^3.

F= polystyrene to sand ratio, % by volume.

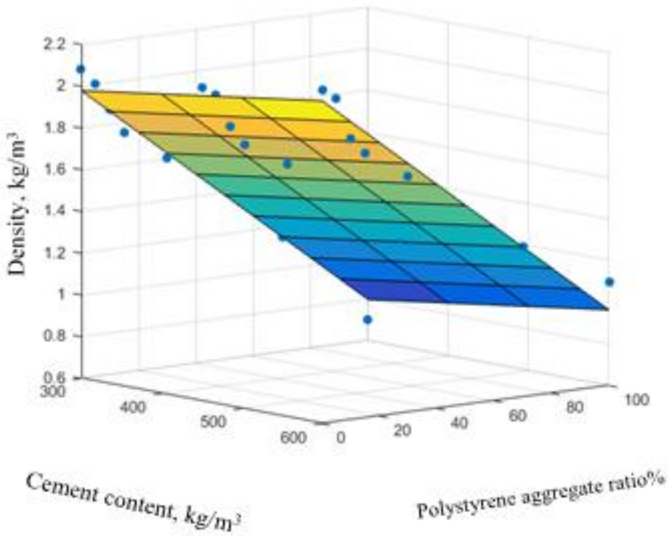

Fig. 11. Regression analysis between the density, cement content and polystyrene aggregate to sand ratio.

Water Absorption:

The Water Absorption (WA) for each concrete C1, C2 and C3 with different polystyrene aggregate ratio combinations after 2 hr, 24 hr and 7 days immersion in cold water is shown in **Figure (12).** Obtained that the increase of the polystyrene aggregate ratio increases the WA of the concrete. Also, WA decreases with an increasing of the cement content at the same polystyrene aggregate ratio. For C1 concrete, with increasing the polystyrene aggregate content from 0 % to 100%, the water absorption increases from 4.8 to 9.9 % at 2hr, from 5 to 10% at 24hr, and from 5.8 to 11.2 at 7 days. While, for C2 concrete, water absorption increases from 3.6 to 9.4 % at 2hr, from 4 to 9.6% at 24hr, and from 4.8 to 10.8% at 7 days, due to increasing the polystyrene aggregate content from 0% to 100%.

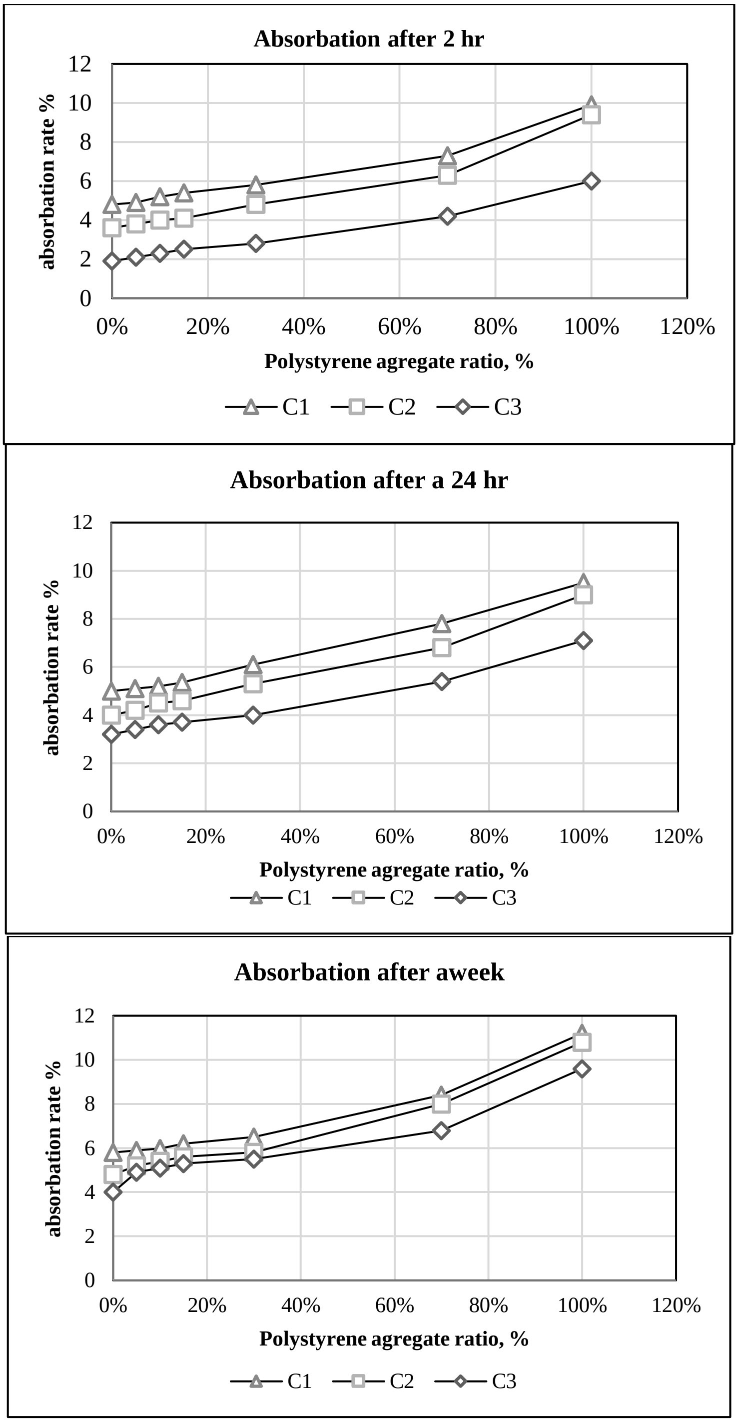

Fig. 12. Effect of polystyrene aggregate ratio on concrete mixtures water absorption.

Also, increasing the polystyrene content (from 0 to 100%) increasing the water absorption of C3 concrete, from 1.9 to 6 % at 2hr, from 3.2 to 7.1% at 24hr, and from 4 to 9.6 at 7 days. This may be explained by the fact that; the cement matrix apparently better encapsulates with polystyrenes particles spatially at higher cement content. Therefore; the C3 concrete absorb less water than the C2 and C1 concretes.

24-hour water absorption values fall within the range of values for cement concrete compounds produced at a similar density **(Gao, Y. L. 2013).** The water absorption values indicate that the polystyrene concrete has low water attraction.

Figure (13) shows the relationship between the Water Absorption values and the concrete density. A strong correlation is obtained as given in **Figure (13)**

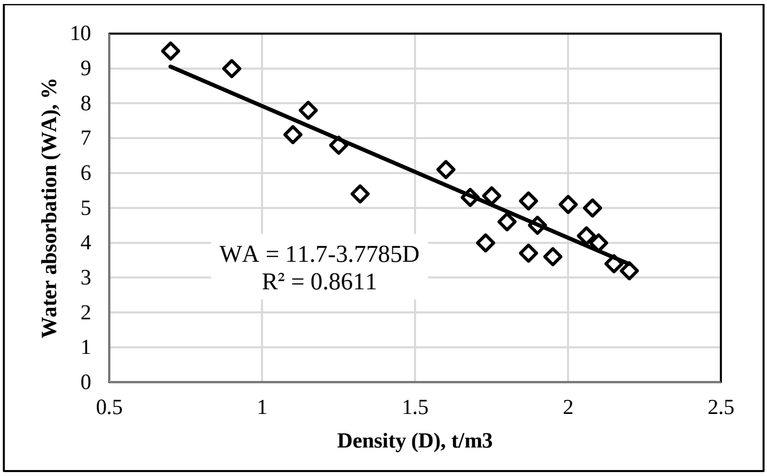

Fig. 13. Relationship between the Water Absorption and concrete density at 24 hours.

Thermal conductivity:

The thermal conductivity of the concrete with respect to the polystyrene aggregate content is presented in **Figure (14)** The results show that an increase of the polystyrene aggregate content decreases the thermal conductivity of the concrete. Also, thermal conductivity increases with the increasing the cement content at the same polystyrene aggregate content.

For C1 concrete, with increasing the polystyrene aggregate content from 0 % to 100%, thermal conductivity decreases from 0.90 to 0.24 W/m˚K. While, for C3 concrete, with the increase of polystyrene aggregate content from 0% to 100%, thermal conductivity decreases from 0.97 to 0.32 W/m˚K.

Also, the thermal conductivities mixture C3 are larger than the results in mixtures C2 and C1. The relationship between the thermal conductivity and the concrete density is diplayed in **Figure (15)** The thermal conductivity is decreasing while the density decreases with the increasing of polystyrene ratio. The thermal conductivity increases with a polynomial function of the apparent density.

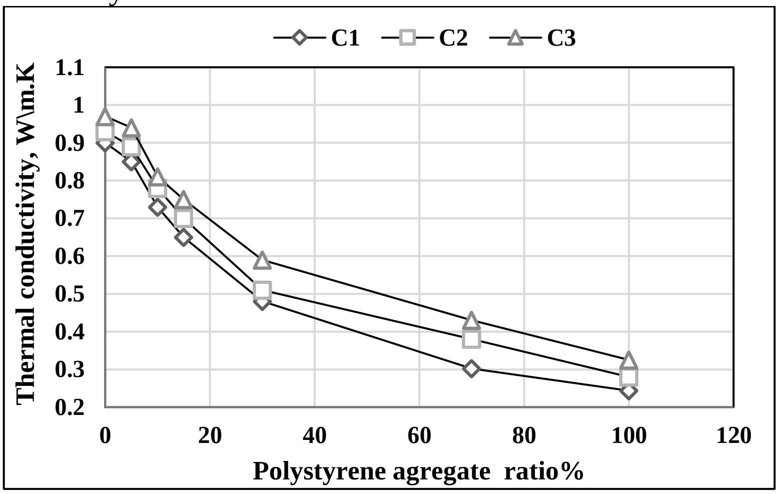

Fig. 14. The relationship between thermal conductivity and polystyrene aggregate ratio.

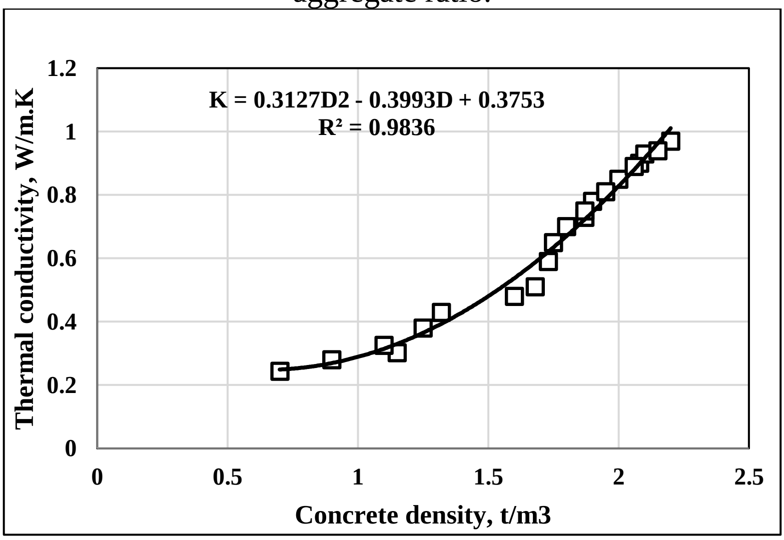

Fig. 15. The relationship between thermal conductivity and concrete density.

A regression analysis was done to determine the relationship between thermal conductivity, cement content and polystyrene ratio to the sand ratio of concrete as shown in Figure (18). Strong correlation is obtained as follow:

$$K= 0.801+9.92*10^{-8}C^2+8.19*10^{-5}F^2+2.25C-0.014F \qquad (8)$$

$(R^2= 97.9)$

Where:

K= concrete thermal conductivity, W/m.°K

C= cement content, kg/m^3

F= polystyrene to sand ratio, % by volume.

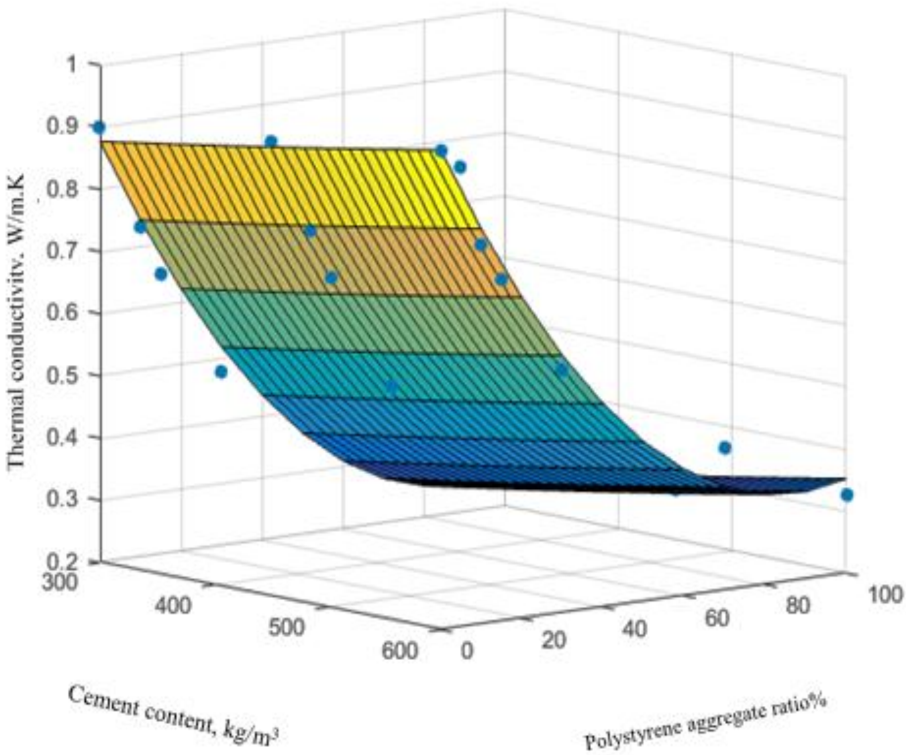

Fig. 18. Regression analysis of thermal conductivity, cement content and polystyrene aggregate.

CONCLUSIONS AND RECOMENDATIONS

This investigation was carried out to develop a light weight recycled polystyrene concrete. Test results show that:

- the compressive strength for all tested polystyrene concrete decreases with the increase of polystyrene aggregate content.
- the polystyrene concrete with cement content 600, 450 and 300 kg/m^3 can be used as a material to make caring bricks up to 70 %, 30% and 15% polystyrene aggregate content, respectively.
- Concrete mixtures with polystyrene content above 70%, 30% and 15% were accepted as non-carrying material for concrete with cement content 600, 450, 300 kg/m^3, respectively.
- the density for all tested polystyrene concrete mixtures decreases with the increase of polystyrene aggregate content. This reduction of density compared with the normal concrete can be considered as an advantage. Due to the reduction of load which subjected to the ground especially on weak soil.
- Based on the obtained data for water absorption all the concrete mixtures were suitable for used inside and outside door.
- All concrete mixtures with high polystyrene content had a low thermal conductivity between 0.24 and 0.32 W/m.K. This gives the concrete a advantage than ordinary concrete because of the significant energy savings.

In future studies, it is recommended to study the engineering parameters of concrete boards and blocks to determine the appropriate use.

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الملخص العربي

القياسات الهندسية لخلطات الخرسانة و البوليستيرين المعاد تدويرها

د. محمد إبراهيم نصر مرسى* و د. أحمد تركي أحمد جيلانى*

تهدف هذه الدراسة الى دراسة تأثير إعادة استخدام مخلفات البوليستيرين (حيث انها تعد من احد الملوثات الصعبة المعالجة الناتجة من تعبئة المواد الغذائية و الاجهزة الكهربائية)على خواص الخرسانة الاسمنتية لتحديد اوجه الاستخدام المناسبة فى صناعة مواد البناء.

تم تجميع كمية من البوليستيرين الناتج من الاجهزة الكهربائية و تقطيعها الى حبيبات لاستخدامها كبديل لركام الخرسانة و بناء على ذلك تم تصميم ثلاثة خلطات خرسانية محتوى الاسمنت فى كل منها هو ٣٠٠ ، ٤٥٠ و ٦٠٠ كجم / م ٣ و محتوى الماء فى كل منها ٠,٤٥ كجم /كجم اسمنت.

تم احلال الرمل المستخدم حجميا فى كل خلطة من الخلطات السابقة بنسب ٪ ، ٥٪ ، ١٠٪ ، ١٥٪ ، ٣٠٪ ، ٧٠٪ و ١٠٠٪.

و قد اوضحت النتائج الاتى:

- انخفاض كلا من أجهاد الضغط و الكثافة ومعامل التوصيل الحرارى لخرسانة البوليسترين بزيادة نسبة احلال الرمل بحبيبات البوليسترين.
- ازداد معدل تشرب المياه بزيادة محتوى البوليستيرين فى الخرسانة
- وجود علاقة ترابط قوية من الدرجة الثانية بين كل من اجهاد الضغط و معامل التوصيل الحرارى و محتوى الاسمنت و نسب احلال الرمال بالبوليستيرين ، وو جود علاقة ترابط قوية من الدرجة الاولى بين كل من كثافة الخرسانة و محتوى الاسمنت و نسبة احلال الرمل بالبوليستيرين.
- و يمكن استخدام خرسانة البوليسترين عند محتويات اسمنت ٦٠٠ و ٤٥٠ و ٣٠٠ كجم / م ٣ كمواد لتصنيع مواد البناء الحاملة عند نسب الاحلال الاتية ٧٠٪ و ٣٠٪ و ١٥٪ من محتوى البوليسترين الكلي لمحتويات الاسمنت السابقة على التوالي. و يمكن استخدام الخلطات الخرسانية ذات المحتويات البوليسيرين الاعلى من ٧٠٪ و ٣٠٪ و ١٥٪ مع محتوى أسمنت ٦٠٠ ، ٤٥٠ ، ٣٠٠ كجم / م ٣ على التوالي كمواد مالئة لتصنيع الطوب الغير حامل.
- و تشير النتائج الى ميزة استخدام هذه الخرسانات فى صناعة مواد البناء نظرا للانخفاض المعنوى فى كثافتها مما يؤدى الى خفض الاحمال الانشائية للحوائط بنسبة كبيرة تتيح لها المقدرة على المنافسة خاصة فى الاراضى ذات التكوين الضعيف.

***مدرس- قسم الهندسة الزراعية و النظم الحيوية، كلية الزراعة الشاطبي ، جامعة الأسكندرية، مصر**

- استناداً إلى البيانات التي تم الحصول عليها من اختبار الامتصاص وجد ان جميع الخلطات الخرسانية تصلح للاستخدامات الداخلية و الخارجية فى المبانى.
- استنادا الى النتائج التى تم الحصول عليها من اختبار معامل التوصيل الحرارى وجد ان جميع الخلطات الخرسانية ذات محتوى البوليستيرين العالى لها معامل توصيل منخفض يتراوح بين ٠,٢٤ و ٠,٣٢.وات/م.درجة كلفن و ذلك عند محتوى بوليستيرين ١٠٠%. مما يعطى هذه الخرسانة قدرة تنافسية بالنسبة للخرسانة العادية و ذلك نظرا للوفر الكبير فى الطاقة اللا زمة لتشغيل هذه المنشئات .