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Polystyrene Lightweight Concrete (Polyconcrete)

خرسانة البوليسترين الخفيفة

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Abstract

This paper handles the characteristics of new lightweight concrete consisting of polystyrene, sand, cement and water. Through this paper it has been proven that the proposed mix is very reliable giving strengths of up to 200 kg/cm^2 with a low density. The mechanical and chemical properties are discussed in order to study the behaviour of the polystyrene under different environments (i.e. field usage). The mix workability is very high at a very low water/cement ratio (down to 0.35). This work can be considered a new line of research for lightweight concrete as the mixing method is very simple, relatively inexpensive and does not need complex machinery systems.

ملخص

يتناول هذا البحث خصائص الخرسانة الخفيفة المصنوعة بطريقة مستحدثة من البوليستيرين والرمل والإسمنت والماء. خلال هذا البحث تم الوصول إلى أن هذا الخليط عملي جدا حيث أنه يعطي قوة تصل إلــى ١٩٠ كجم/سم^٢ وبكثافة قليلة. كما تم مناقشة الخصائص الميكانيكية والكيميائية للخليط ومكوناته للوصول إلى مجالات استخدامه ميدانيا. ويتميز هذا الخليط بانخفاض نسبة الماء/ الإسمنت والتي تصل إلى 0.32 مما يحافظ على خصائص الإسمنت.

في نهاية البحث تم تقديم طرق عملية وميسرة لتصميم الخلطات التي تحتوي على مادة البوليستيرين وكذلك للطوب الخفيف. ويعتبر هذا الخليط خطاً جديداً لصناعة الخرسانة الخفيفة حيث أن تصنيعه يحتاج إلى طرق بسيطة وممكنة.

Nomenclature

C Cement contents (kg/m^3)
P/S "Polystyrene / Sand" ratio
P/C "Polystyrene / Cement" ratio
W/C "Water / Cement" ratio
Fcu Compressive strength of concrete (N/mm2)

1. Background

The essential characteristic of lightweight concrete is its porosity, which results in low apparent specific gravity. In concrete construction, self-weight represents a very large portion of the load on the structure, and there are considerable advantages in reducing the density of concrete. Furthermore using lightweight concrete improves construction and handling techniques; larger units are often desirable; obviously transportation and on-site handling would be made more economical. Lightweight concrete reduces the cost of formwork and steel and it also increases productivity. Giving better thermal insulation than ordinary concrete. The practical range of densities of lightweight concrete is between about 300 and 1850 kg/m^3 [1]

Concrete weight is lightened by;

- The introduction of air as air bubbles of rather coarse size (1-3 mm diameter) in the mortar, this is called “aerated concrete”.
- The introduction of air by using a special agent, this is called “air-entrained concrete”.
- The use of lightweight aggregate as a substitute to normal aggregate.

The process of manufacturing lightweight concrete is very costly as complex machinery, chemicals and/or expensive lightweight aggregate are used. This has lead to a search for a substitute for expensive lightweight aggregate. The idea of using Polystyrene particle as a substitute of air bubbles (lightweight aggregate) has been introduced, as the density of Polystyrene is nearly negligible (16-27 kg/m^3) when compared to that of concrete aggregates (1700-2000 kg/m^3).

An intensive literature survey on light weight concrete has been carried out to seek references to the use of polystyrene in concrete mixes, more than 3000 websites were visited over the internet, nothing was directly related to the topic of this paper. Accordingly extensive work is needed to explore all chemical, physical and structural properties.

An attempt has been made to explore, provisionally, the structural, physical and chemical behaviour, advantages and disadvantages of Polystyrene concrete (Polyconcrete) by carrying out an extensive experimental work at the Islamic University Materials Laboratory.

The Polyconcrete mix is very critical to water/cement ratio; simply no mix was possible for water/Cement ratio above 0.42, above this ratio polystyrene has been segregated leaving the mortar.

2. Experimental Programme

Polystyrene, sand, cement and water with different ranges for each component were tested at the Islamic University, Faculty of Engineering, "Materials Testing Laboratory". Table (1) shows the ranges established in the study.

Table 1: Ranges established in the research.

Material	Range	Remarks
Cement	200 - 600 kg/m^3	
Sand	150-700 kg/m^3	
Polystyrene	0.3-1.2 m^3/m^3	when mixed it is compacted down to 70 % 0f it original size, approximately
Water/Cement	0.35-0.45	No mix is possible beyond this range

The materials used in preparing all of the concrete specimens were as follows:

Cement: Ordinary Portland cement, manufactured by the Israeli company "Nesher" with fly ash of up to 10 % of cement weight, and conforms to ASTM C150, it is the only cement type available in Gaza market. Table (2) shows the mechanical properties of the used cement.

Table 2: Mechanical properties of cement.

	Test	Result
Compressive strength	**3-day**	**200**
	7-day	**250**
Normal consistency (%)	25.6	Normal consistency (%)
Initial setting time	135 min	Initial setting time
Final setting time	280 min	Final setting time
Fineness	3550 cm^2/gr	Fineness
Soundness	1.5 mm	Soundness

Aggregates: Fire retardant Polystyrene (F-Grade) round shape and glazed in texture, with a diameter of 1.5 to 3 mm obtained from BASF company in Germany.

Workability Aids: no workability aids or admixtures were used throughout the study.

Specimens

For compressive strength evaluation, cubic samples of 10 cm were used.

Mix Proportions and specimen preparation

132 concrete mixes, 2 –3 samples for each mix were used as shown in Table (3) using water/cement ratios of 0.3 up to 0.45 with different cement contents of 238 kg/m^3 up to 600 kg/m^3. The volumetric base for calculating all components was used (i.e., to fit one cubic meter of the mix).

Curing

The 265 Specimens were cured according to C&CA, 1978 procedures [9] in a curing tank at a temperature of 25° for 28 days.

Table 3: Concrete mix characteristics showing part of the 265 experimental results performed at IUG laboratory.

Mix No.	Cement kg/m^3	Sand kg/m^3	Polystyrene kg/m^3	Polystyrene m^3/m^3	Water kg/m^3	P/C by vol	P+S/C By vol	P/S by vol	Stress Kg/cm^2	Density kg/m^3	Theoet. Density
2	238	761	7	0	95	5	11	1	35	1600	1101
4	242	581	9	0	97	6	11	1	28	1460	928
6	250	696	10	0	100	5	10	1	41	1360	1057
8	250	557	12	0	100	6	10	2	30	1220	919
22	256	513	9	1	103	6	10	2	21	1385	881
24	256	513	9	1	103	6	10	2	54	1385	881
26	256	513	9	1	103	6	10	2	54	1385	881
28	270	337	11	1	108	7	10	3	41	1140	726
36	285	356	10	1	128	6	9	3	53	1175	780
38	285	379	10	1	114	6	9	3	37	1180	789
40	285	356	10	1	128	6	9	3	49	1175	780
48	292	350	11	1	117	6	9	3	39	1250	769
50	294	588	8	0	118	5	9	1	65	1540	1008
70	300	380	14	1	120	6	8	3	42	1200	814
72	300	333	15	1	120	6	8	3	32	980	768
112	327	327	10	1	131	6	8	3	61	1220	794
114	327	327	10	1	131	6	8	3	60	1220	794
116	332	416	9	1	150	5	7	2	73	1330	907
120	334	478	9	0	134	5	7	2	78	1450	954
138	347	288	10	1	139	5	7	3	56	1210	785
142	350	508	11	0	140	4	7	2	135	1475	1009
166	380	457	8	0	152	4	6	2	75	1460	997
168	386	483	8	0	155	4	6	2	65	1500	1032
170	389	276	10	1	156	5	6	3	83	1212	831

... *Table (3) Continued*

Mix	Cement	Sand	Polystyrene		Water	P/C	P+S/C	P/S	Stress	Density	Theoet.
No.	kg/m^3	kg/m^3	kg/m^3	m^3/m^3	kg/m^3	by vol	By vol	by vol	Kg/cm^2	kg/m^3	Density
172	389	276	10	1	156	5	6	3	68	1212	831
174	391	391	8	0	176	4	6	2	76	1344	965
176	400	604	9	0	160	3	6	1	116	1520	1173
178	400	483	11	0	160	3	6	2	73	1300	1054
180	400	403	12	0	160	4	6	2	70	1238	975
202	450	328	12	0	180	3	5	3	87	1200	970
212	489	367	8	0	196	3	4	2	57	1131	1060
214	500	543	8	0	200	2	4	1	130	1548	1251
236	550	410	9	0	220	2	3	2	154	1430	1189
265	600	385	9	0	240	2	3	2	60	1270	1234

3. Polyconcrete Properties

Polyconcrete is lightweight concrete made with cellular polystyrene beads "particles" as aggregate. Unlike aerated concrete, which requires autoclaving to obtain both lightness and strength. It can be used for both in-site and pre-cast components. The lightweight aggregate can be made at the concrete works, using raw expandable polystyrene beads. Since polystyrene particles are uniform, and relatively course, the structure can range from that of no-lines concrete (density 300 kg/m^3 or less) to that of fully compact concrete (density 1000 kg/m^3 or more).

3.1 Materials

3.1.1 Expanded Polystyrene aggregate

The aggregate is made from raw Polystyrene, which consists of spherical beads containing an expanding agent. When the glossy beads are heated by live steam they soften and expand, forming a cellular structure. This process is best carried out when the aggregate is required, since this minimises transport costs. The expanded beads have an apparent density of about 16-27 kg/m³, and 125 kg raw Polystyrene occupies about 0.3m³ shipping space- yields 10m³ aggregate, enough for 6 m³ compacted concrete [2].

Before expanded Polystyrene beads can be used as aggregate they must be left for more than four hours to take up air. The beads are inelastic, and do not recover when deformed, yet they are able to withstand the stresses when the concrete is mixed and compacted.

The particle size-distribution of expanded Polystyrene aggregate is narrow in comparison with those of most other types of aggregate [see plate (1)]. It is possible to broaden the distribution by mixing courser and finer grades of Polystyrene. This has little effect on the properties of either the fresh or hardened concrete.

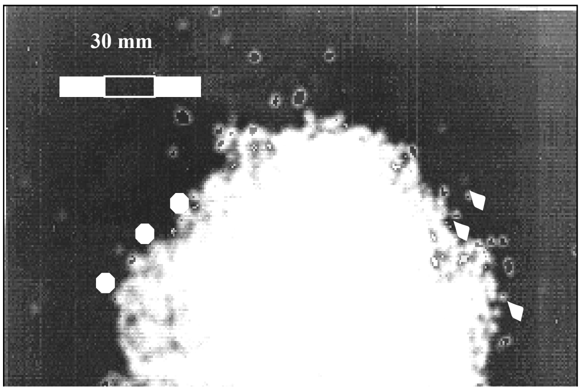


Plate 1: Polystyrene Particles.

Expanded Polystyrene beads are non-absorbent, since their cells are closed. They are easily compressible, and hence their direct contribution to the compressive strength of the concrete is negligible; their primary function is to act as a filter in the concrete mix. However the high thermal resistivity of the concrete and some of its desirable properties result from the presence of the beads.

Polystyrene has so many commercial names such as "Styropor" and "Karkal". It is used mainly as insulating materials, and is manufactured in particles of small diameters up to 4mm (after expansion process). The particles used in this work are the expanded fire retarding type of a diameter range of 1.5mm to 3mm.

Testing water absorption of Polystyrene lead to the conclusion that the maximum absorption by mass fraction is only 0.05. Polystyrene does not contain any ingredients, which would affect its properties by the extraction of water

As Polystyrene is a cellular material, it represents a larger area for chemical attack. Table [4] shows the effect of different chemicals on the Polystyrene material [2].

Table 4: Chemical Resistance of Polystyrene to different materials.

Substance	**Effect**	**Substance**	**Effect**		**Effect**
Sea water	+	***Fuming acids***		***Inorganic building materials***	
Water	+	Nitric acid	-	Anhydrite	+
Alkalis		Sulfuric acid	-	Cement	+
Ammoniacal solution	+	***Weak acids***		Gypsum	+
Bleach (hypochlorite & hydrogene peroxide)	+	Carbonic acid	+	Lime	+
Lime water	+	Citric acid	+	Sand	+
Potassium hydroxide solution	+	Humic acid	+	***Organic building materials***	
Soap solution	+	Lactic acid	+	Bitumen	+
Sodium Hydroxide solution	+	Tartaric acid	+	Cold Bitumen (water type)	+
Dilute acids		***Gases***		Cold Bitumen (solvent type)	-
Acetic acid 50%	+	*a. Inorganic*		***Vapours***	
Formic acid 50%	+	Ammonia	-	Camphor	-
Hydrochloric acid 7%	+	Bromine	-	Naphtalene	-
Hydrochloric acid 18%	+	Chlorine	-	***Miscl. Organic compounds***	
Hydrofluoric acid 4%	+	Sulphur dioxide	-	ACetone	-
Hydrofluoric acid 40%	+	*b. Organic*		Acetonitrile	-
Nitric 13%	+	Butadiene	-	Acrylonitrile	-
Nitric acid 50%	+	Butane	-	Dimethylformamide	-

… Table (4) Continued

Substance	Effect	Substance	Effect		Effect
Phosphoric acid 7%	+	Butene	-	Esters	-
Phosphoric acid 50%	+	Ethane	+	Ethers	-
Sulphuric acid 10 %	+	Ethene	+	Fluorocarbons	-
Sulphuric acid 50%	+	Ethyne	+	Halocarbons	-
Aliphatic hydrocarbons		Methane	+	Ketones	-
Cyclohexane	-	Natural gas	+	Olive oil	+
Diesel, Fuel Oil El	-	Propane	+	Paint solvent	-
Gasoline	-	Propene	+	Tetrahydrofuran	-
Heptane	-	Propene oxide	-	***Amines***	
Hexane	-	***Liquefied gases***		Aniline	-
Mineral spirit 55-95C	-	***a. Inorganic***	+	Diethylamine	-
Miniral spirit 155-185C	-	*Ammonia*	+	Ethylamine	+
Petroleum jelly	+	Hydrogene	+	Trithylamine	-
White oil	-	Nitrogen	+	***Concentrated acids***	
Alcohols		Oxygen	+	Acetic acid 96%	-
Butanol	-	Rare gases	+	Formic acid 99%	+
Cyclohexanol	+	Sulphuric dioxide	-	Hydrochloric acid 36%	+
Diethylene glycol	+	***b. Organic***		Nitric acid 65%	+
Ethanol	-	Butadiene	-	Propionic acid 99%	-
Ethalene glycol	+	Butane	+	Sulphuric acid 98%	+
Glycerol	+	Butene	-	***Anhydrides***	
Coconut fatty alcohol	+	Ethane	+	Acetic anhydride	-
Methanol	-	Ethene	-	Carbon dioxide, solid	+
Propanol 1&2	-	Ethene oxide	-	Sulphur trioxide	-
Diethylene glycol	+	Ethyne	-		
		Methane	+		
		Natural gas	+		
		Propane	-		
		Propene	-		

[+ve sign means no effect & -ve sign means damaging effect]

The thermal conductivity of Polystyrene is very low [3,4] which improves the thermal characteristics of concrete when used as a substitute for the coarse aggregate.

The flammability and flame spread of aged Polystyrene is retarded to an extent that it can be classified as “flame retardant”. The foam extinguishes itself as soon as the ignition flame is removed [see Plate 2]

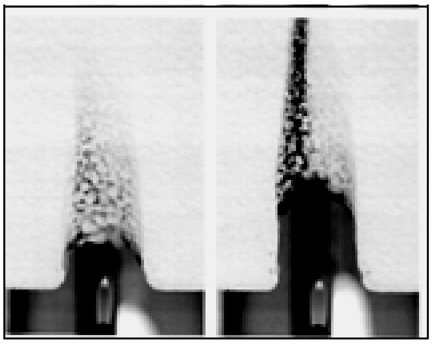


Plate 2: Flame Spread of Aged Polystyrene.

3.1.2 Cement

Careful consideration of the characteristics of Polystyrene has lead to the conclusion that all forms of cement can be used for Polyconcrete. Because of the low specific thermal capacity and high thermal resistivity of the Polystyrene, the heat of hydration of the cement causes greater and rapid temperature increase than in concrete made from dense aggregate. This effect is often desirable, since it accelerates the hardening of the fresh concrete. In all circumstances the temperature of hydration inside concrete must not exceed 70°C [5] and it has to be noticed that the Polystyrene particles will swell at 80°C causing damage to concrete components. The hydration temperature could be prevented by using suitable cement (e.g. Ordinary Portland Cement) and by reducing the thickness of the fresh concrete.

3.1.3 Sand

All forms of fine aggregate are suitable for Polyconcrete, provided they are compatible with cement. This includes natural sand, crushed rock and both dense and lightweight mineral aggregates.

3.1.4 Admixtures

Admixtures modify the properties of Polyconcrete in the same way as those of normal dense concrete. However, special caution is necessary with accelerators and retarders, since the higher temperatures in fresh Polyconcrete can enhance their effects: if not adequately tested, or added in the wrong proportions, such admixtures can result in useless mixes.

The most effective and economical method of increasing the strength of Polyconcrete is to raise the proportion of cement. However this entails an increase in density, and may cause increased drying shrinkage.

4. Analysis & Interpretation of the Experimental Results

Generally speaking, all lightweight concrete behaviours can be viewed in a way similar to that of normal concrete, although quantitatively there are significant differences.

4.1 Sensitive Mix and Design Parameters:

Analyses were performed for the different parameters involved in the Polyconcrete mix. The parameter Polystyrene/sand (P/S) by volume has been found to be the most suitable and sensitive parameter in interpreting different correlation as it has proved to give a strong base for mix behaviour and design [see figure (1)]. The parameter Polystyrene / Cement (P/C) by volume was also tested thoroughly; it proved to be less sensitive in representing the mix characteristics [see figure (2)].

4.2 Compressive Strength

Figure (1) shows the relationship between the compressive strength of the Polyconcrete and the ratio between the polystyrene/sand (P/S) by volume for different cement contents. The effect of cement content can be seen clearly from the trend-lines shown, i.e. the more the cement content the more the strength.

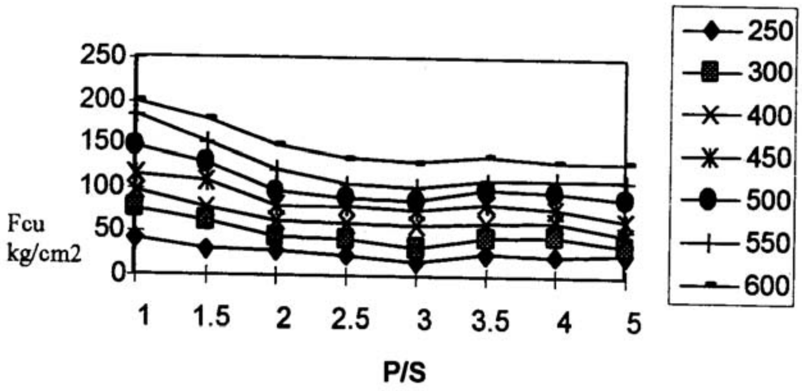
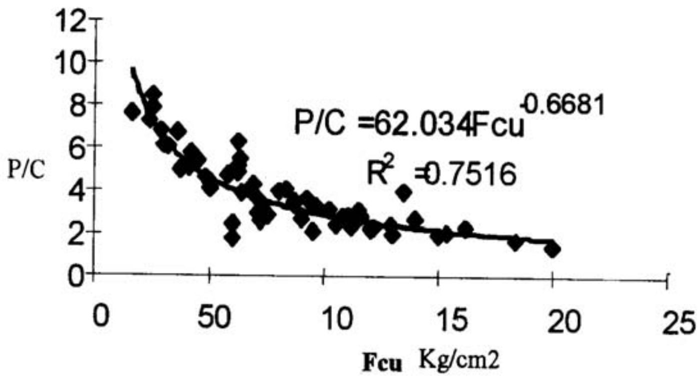


Figure 1: Relationship between Fcu & P/S For diff. cement contents.



The compressive strength can reach 200 kg/cm² when the amount of polystyrene proportions is relatively low and the content of cement is relatively high, as a result the density approached 1550 kg/m³. While for P/S = 5 with cement content =600 kg/m³ the strength gained was 15 N/mm² with a density of 1200 kg/m³. Leading to the conclusion that this mix can be used for structural and non-structural members and for load bearing and non-load bearing members.

The effect of cement content is illustrated in Figure (2). This relationship is significantly affected by the P/S parameter and can not be interpreted alone, i.e. for a given proportion of P/S; the more the cement content the more the concrete strength, and for a given cement content; the more proportion of P/S the less the compressive strength.

4.3 Compaction and Density

Mixing precisely measured quantities of Polystyrene and mortar to give one cubic meter would result in giving a total volume less than 1 m³ (on average it would give 0.65 m³ to 0.8 m³). This phenomenon takes place due to the compressibility of the polyester material. The calculated (theoretical) density of the mix versus the actual density has been studied and an acceptable regression was established, as shown in Figure (3). It can be seen that the actual density is larger than the theoretical density. This has proved to be vital in the mix design in obtaining specific densities and characteristics.

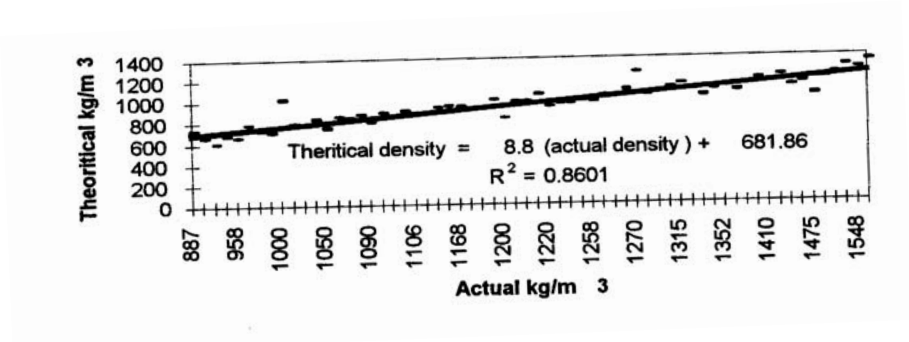
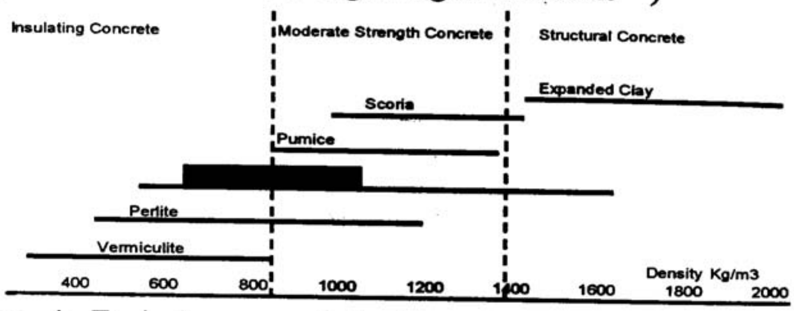


Figure 3: Relationship between theoretical & actual density.

Figure (4) shows typical ranges of densities of concrete made with various lightweight aggregates including Polyconcrete (Polyconcrete range has been added to the original figure of Neville [1])



4.4 Water Cement Ratio & Workability

During the course of this research it was clearly noticed that Polyconcrete is very workable even at a water cement ratio of 0.35, the existence of the glazed smooth rounded beads of the polystyrene helps significantly in increasing the workability, i.e. the mix is different from the conventional concrete mix, where light weight concrete mixes are usually not workable at a low w/c ratio [7]. Having the cement content range from 200-300 kg/m³ gives a workable mix at a w/c ratio of 0.4. It has also been noticed that when using the workability tests such as; the slump test or compacting factor test, careful consideration should be made to the fact that these tests should be interpreted separately and not to be compared with conventional concrete as there readings and behavior are completely different.

4.5 Admixture

Generally speaking all admixtures used in concrete mix design are admissible in Polyconcrete. Careful consideration has to be taken to the chemical compositions of the used admixture. Guidelines can be followed making use of Table (4) where all chemicals affecting the Polystyrene beads has been gathered.

High temperatures caused by retarders and accelerators has to be carefully dealt with as the Polyconcrete mix temperatures must not exceed 80°C in order to avoid unexpected swelling of the polyester particles.

5. Advantages & disadvantages of Polyconcrete

Table (5): shows the advantages and disadvantages of the Polyconcrete:

Table 5: Advantages and disadvantages of the Polyconcrete (as established throughout this work).

	Advantages	Disadvantages
Weight	Light; down to 600kg/m^3	
Strength	Ranging from 2 to 20 N/mm^2	
Resistance to chemicals		Sensitive to most petroleum products
Field Applications	Suitable for Structural and non-structural members	Not suitable to be used as prestressed concrete
Cost	Less than most available lightweight concretes	
Acoustic resistance	The best among all other lightweight concrete	
Fire Resistance	Burning without flames	Starts to evaporate above 300°C
Workability	Very workable at low w/c ratio	
Mix consistency	Consistence for w/c 0.32 to 0.45	Stable up to 30 minutes after mixing
Thermal insulation	The best among all other lightweight concrete	
hardening time of fresh concrete	Less than normal concrete	

6. Economical Consideration

According to the local cost of the mix compositions in Gaza, the cost per $1m^3$ varies, mainly, according to the amount of polystyrene used, the most expensive mix does not exceed 70% of the cost of the conventional concrete and 50% of light weight concrete (for example aerated light weight concrete).

7. Mix Design

Polyconcrete is made by mixing the lightweight aggregate (expanded Polystyrene beads) with cement, sand and water in a conventional mixer. Its density can be adjusted within close limits to anywhere in the range 500-2000kg/m^3, so that it can be used for insulating screeds and renderings, non-load-bearing and load-bearing components.

Within the normal density range of non-structural lightweight concrete the uniformly dispersed expanded Polystyrene beads occupy much of the volume between 600kg/m^3 and 800kg/m^3 where compressed aggregate occupies 60-80%, nearly all the remaining space being filled by the mortar. Since this mortar determines the mechanical properties of the material it generally has ahigh cement content. The consistency of fresh Polyconcrete is not adequately measured by means of the tests generally employed for normal concrete, e.g. various forms of slump tests [8]. The compacting factor test can be applied as a measure of consistency and workability, but the values obtained need to be interpreted differently from the values of normal concrete. The differences arise from the high proportion of the very regular aggregate, which gives a mix that is lean, and not very cohesive, but offers little resistance to flow.

7.1 Proposed Mix Design Procedures

1. Determine the compressive strength needed.
2. From Figure (2) determine the volumetric proportions of Polystyrene to cement content.
3. Determine the cement content for an assumed P/S from Figure (5)

4. Use Figure (1) to check the strength for the calculated cement contents and for the assumed P/S. If the Fcu read from Figure (1) equals or is greater than the needed Fcu, then the design proportions are reasonable and would give the needed compressive strength.
5. Calculate the theoretical density of the mix (Use an acceptable value of 20 kg/m^3 as the density of polystyrene aggregates). Using Figure (3) the actual density can be obtained.

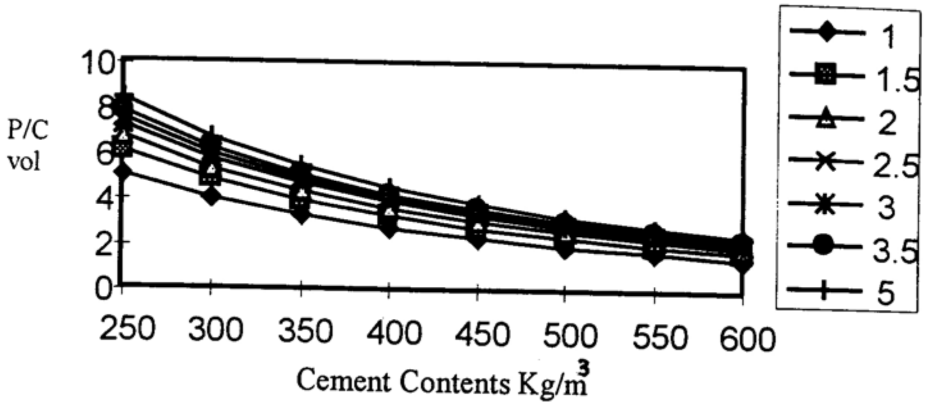


Figure 5: Design Curve for mix propotions for different P/S vol.

7.2 Hollow Block design

A sample design curve was plotted for a 15cm x 20cm x 40cm hollow block, which can be used as a load-bearing block or for a ribbed slab. The density of such a block is less than 50% of those made in the conventional way. To determine the P/S ratio corresponding to certain Fcu for a 15cm block, Figure (6) can be used directly for cement contents of 250 kg/m^3 and for any value of P/S, alternatively the regression equation shown can also be used (Fcu = -1.53 P/S + 14.53)

Plate 3: Polyconcrete Blocks.

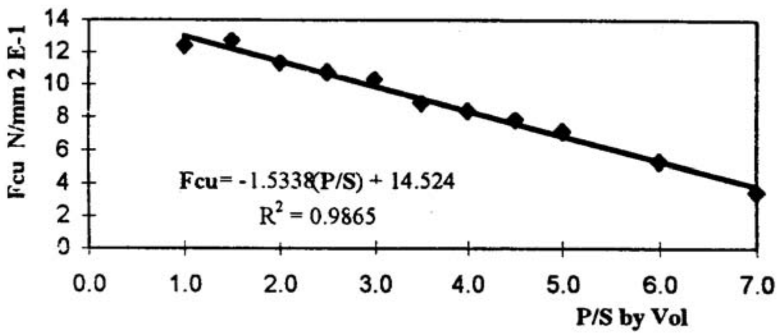


Figure 6: Fcu versus P/S for C = 250kg/m^3 for 15cm blocks acc. to BSI5 Part 1, 1989.

7.3 Batching and Mixing

Accurate batching must be maintained once the mix design has been established for a particular application, otherwise the properties of the concrete will deviate from those required. The expanded Polystyrene aggregate is batched by volume, all other components (except liquid admixtures) by weight.

It is important that the correct amount of water is used since even minor variations in water content can spoil the consistence and workability of Polyconcrete mixes: much careful care is needed than when mixing normal concrete.

As explained freshly expanded Polystyrene beads are easily compressed and damaged, for this reason it is uneconomical and technically undesirable to mix them immediately with cement and water, since more beads would be required and the concrete would not have the desired properties.

Maximum transport time is affected of course by the comparatively rapid rise in temperature in Polyconcrete mixes, and it has been found that the material retains a workable consistency for not much more than 30min after mixing. Proper treatment of Polyconcrete while it is setting and hardening is even more important than it is for normal concrete. The total water/ cement ratio is comparatively low, so that losses of water cause more noticeable effects. Keeping the green concrete moist, and subsequently slow drying out and cooling are essential for good strength, and at the same time delay drying shrinkage, thereby reducing the danger of cracking.

7.4 Mechanical Properties of Polyconcrete Mix

The density of the mix can be adjusted between 700-1200 kg/m^3. Its strength varies from 30-200 kg/cm^2 mainly depending on the components of mortar especially cement contents.

7.5 Consistency and workability

Fresh Polyconcrete contains a high proportion of spherical aggregate, and is not very cohesive: it has a crumb like consistency. Various tests for consistence or workability has been applied to it, but the consistency categories often applied to normal concrete have been found to be generally inapplicable.

7.6 Temperature of Fresh and Green Concrete

Polyconcrete has one especially noticeable characteristic: because of its low specific thermal capacity and high thermal resistivity, the heat of hydration of the cement causes greater and rapider temperature increases than in concrete made from dense aggregate. This effect is often desirable, since it accelerates hardening of the fresh concrete, and is particularly useful in the manufacturing of pre-cast components[9] . However, in concrete 20cm thickness or more the temperature may easily reach 70°C or more, depending on the surrounding temperature and the mix, and this can exceed 80°C. At the latter temperature the expanded Polystyrene aggregate begins to swell, and could damage the structure of the green concrete: this reduces ultimate strength. Excessive temperature rises can be prevented by selecting a suitable type of cement and by reducing the thickness of the fresh concrete

8. Field Applications

It has been established that Polyconcrete can be used for non-structural components such as; hollow blocks ribbed slabs (following this work; ten buildings in Gaza were constructed using Polyconcrete hollow blocks, and proved to be extremely efficient. This has lead to recognising Polyconcrete as an acceptable building material by concerned establishments), thermal and sound insulation slabs, frost resistance slabs, screed and roof slopes and; structural members such as; pre-cast lightweight components and lightweight blocks.

9. Conclusions

This paper has explored the characteristics of new lightweight concrete consisting of polystyrene, sand, cement and water. Through this paper it has been proven that the proposed mix is very reliable giving strengths of up to 200 kg/cm^2 with a low density. The mechanical and chemical properties have, also, been discussed in order to study the behaviour of polystyrene under different environments (i.e. field usage). The mix workability is very high at a very low water/cement ratio (down to 0.35).

A new method for designing Polyconcrete mixes has been introduced in a simple, yet practical and tangible way.

This work can be considered a new line of research for lightweight concrete as the mixing method is very simple, relatively inexpensive and does not need complex machinery systems.

It is recommended that further work should be done to cover; permeability, structural behaviour, absorption, freeze and thaw durability, abrasion, and corrosion of steel reinforcements. The mentioned tests are essential to be carried out before the use of Polyconcrete in structural members.

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