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Key words: *lightweight concrete, compressive strength, density, polystyrene, sand, cement, mix proportions*

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THE RELATIONSHIPS BETWEEN COMPRESSIVE STRENGTH AND DENSITY OF POLYSTYRENE LIGHTWEIGHT CONCRETE AND THEIR COMPONENT RATIOS

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The research deals with the compressive strength and density of lightweight concrete, made from polystyrene, cement, sand and water. This type of lightweight concrete is characterized by good thermal insulation, low density and good compressive strength and it is used as a lining material in inclination surfaces and in the production of unloaded building units and elements. The aim of this paper is to suggest mathematical relationships between compressive strength, density and mix proportions. An intensive experimental program has been implemented for this purpose. The investigated variables were the mix proportions, namely, polystyrene to cement ratio (P/C), sand to cement ratio (S/C) and water to cement ratio (W/C). Sixty mixes were produced and tested using five polystyrene to cement ratios (P/C), 0.02, 0.03, 0.04, 0.05, 0.06 four sand to cement ratios (S/C), 2.5, 3, 3.5, 4 , and three water to cement ratios (W/C), 0.35, 0.40, 0.45. From the test results, mathematical relationships were suggested that can be of use in determining mix proportions of polystyrene lightweight concrete based on the required compressive strength or based on the required dry density.

Key words: lightweight concrete, compressive strength, density, polystyrene, sand, cement, mix proportions

INTRODUCTION

Lightweight concrete is considered one of the alternatives that has a great importance in modern buildings. It is one of the most prominent developments in concrete technology and has a wide use in the construction works because of its characteristics that traditional concrete does not provide. It is more economical because of its low density, ranging between (240-1840) kg/m^3 [1] and [2], reducing dead loads and resulting in smaller structural elements. In addition, polystyrene is available locally with low cost, and its waste can be used in abundance, which contributes to reducing environmental pollution. Also, it provides a good thermal insulation, saving the energy needed for cooling and heating, especially, the polystyrene is classified as first-class thermal insulation material. Kohling [3] conducted a research and showed the possibility of using polystyrene as aggregate to manufacture concrete with high thermal insulation. Maura [4] found that the compression strength of polystyrene concrete with densities ranging between (220-460) kg/m^3 is in the range of (0.7–2.3) Mpa, while the modulus of rupture ranges between Mpa (0.3– 0.36). Parton and barbary [5] observed that the properties of polystyrene concrete such as density, compressive strength, modulus of rupture, and thermal insulation mainly depend on the Polystyrene to cement ratio. Sabaa and Ravindrarajah [6] carried out the experimental program using the expanded polystyrene waste in a granular form as lightweight aggregate to produce lightweight structural concrete with the unit weight varying from 1600 to 2000 kg/m^3. The coarse aggregate replacements levels used were 30, 50 and 70%. The results showed that drying shrinkage and creep of polystyrene aggregate concrete increased, whereas compressive strength and modulus of elasticity decreased with decrease in the density of concrete. The compressive strength was found to be more sensitive to the density than the modulus of elasticity. The ultimate creep coefficient for polystyrene aggregate concrete in the density range of 1600 to 2000kg/m^3 was between 1.90 and 2.37 for the concrete with the cement content of 410 kg/m^3. Kuhail and Shihada [7] suggested a recommended way in preparing lightweight polystyrene concrete mixes and proportions for producing homogeneous mixes with compressive strengths ranging between 17 MPa to 25 MPa and densities ranging from 1650 kg/m^3 to 1830 kg/m^3. Kan and Demirbogab [8] observed that, with the increase of cement to EPS beads ratio in the mixes, both density and compressive strength of concretes increased up to 4 and 350 times respectively, when compared to the control sample. Hardened concrete densities and compressive strength varied from 464 to 1940 kg/m^3, and 0.11 to 38.50 MPa, respectively. Slump values of the mixes were changed from 8 to 43 mm. Herki et al. [9] used waste polystyrene as a lightweight aggregate (LWA) to produce lightweight aggregate concrete (LWAC). In this study the WP was shredded to different sizes. Four concrete mixtures in total with varying WP content ratios of 0, 20, 40 and 60% as partial replacement of natural coarse aggregate by equivalent volume was prepared. The water/cement (W/C) ratio of 0.5 was kept constant for all concrete mixtures. Mechanical and durability properties including compressive strength, water absorption (WA) and density was determined for the various concrete mixtures at the ages of 7 and 28 days of

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water curing. According to the results obtained, the utilization of WP in concrete production is possible. Abd et al. [10] carried out an investigation to study the properties, such as compressive strength and tensile strengths of light weight concrete containing Expanded Polystyrene (EPS) beads. The results showed that the amount of polystyrene beads incorporated in concrete influences the properties of hardened concrete. Since the compressive strength less than a certain percentage depending on the amount of replacement. At 28 days, it was found that compressive strength of 5%, 15%, 20%, EPS based concretes compared to control concrete were 41%, 38 %, 25%, respectively. Minh and Phuong et al [11] investigated the effect of properties and volume of the matrix on the properties of lightweight concrete. The results show that properties of structural polystyrene concrete, such as workability and compressive strength, depend on the aggregate size of the matrix. It also shows that decreasing aggregate size of the matrix is the effective way to increase workability and compressive strength of lightweight concrete. Bedekovic et al. [12] showed based on their test results on waste expanded polystyrene lightweight concrete a dependence of the component ratio on the bulk density ranging from 360 kg/m^3 to 915 kg/m^3 and compressive strength ranging from 0.385 MPa to 2.538 MPa.

From the previous studies, it is clear that the researches dealing with the mix design of polystyrene lightweight concrete are very limited. Kuhail and Shihada [7] suggested a procedure for mix design based on the required compressive strength and density. This paper represents a contribution in this field by suggesting number of mathematical relationships between compressive strength and density of polystyrene lightweight concrete and their mix proportions namely, sand to cement ratio (S/C), water to cement ratio (W/C) and polystyrene to cement ratio (P/C), which can be of use to suggest the mix proportions based on the required compressive strength or based on the required dry density. Ubi, Stanley et al. [13] carried an experimental program to develop a mathematical model that will optimize the compressive strength of polystyrene lightweight concrete. The materials used for this study were, ordinary Portland cement, Water, Sand, coarse aggregate and Expanded Polystyrene beads. The study adopted the Scheffe's simplex lattice design for both pseudo and component proportion models to generate their respective mixes. The study showed that using the Scheffe's Pseudo component model, an optimized compressive strength value of 27.920 N/mm^2 can be obtained from a water, cement, sand and coarse aggregate (at 12% partial replacement with polystyrene aggregates) mix ratio of 0.455, 1, 1.820 and 2.980 respectively

EXPERIMENTAL PROGRAM

Mix proportions

An experimental program was implemented including several laboratory tests on compressive strength and dry density of lightweight concrete using sand and polystyrene as aggregate. The investigated variables were the mix ratios of their components. These mixes were accomplished by using three water to cement ratios (W/C) of 0.35, 0.40 and 0.45, five polystyrene to cement ratios (P/C), 0.02, 0.03, 0.04, 0.05, and 0.06, four sand to cement ratios, 2.5, 3, 3.5 and 4. As a result, sixty mixes were produced and tested. Material weights were calculated per cubic meter using the volumetric equation to be as shown in Table 1.

Table 1: Detail of mixes

Mix No.	P/C	Water kg/m^3	Polystyrene kg/m^3	Sand kg/m^3	Cement kg/m^3	Mix No.	P/C	Water kg/m^3	Polystyrene kg/m^3	Sand kg/m^3	Cement kg/m^3
W/C = 0.35 S/C = 2.5						W/C = 0.35 S/C = 3					
2.1.2	0.02	107.36	6.135	766.86	306.74	3.1.2	0.02	101.59	5.805	870.77	290.26
2.1.3	0.03	85.50	7.329	610.74	244.30	3.1.3	0.03	81.80	7.012	701.17	233.72
2.1.4	0.04	71.04	8.119	507.44	202.98	3.1.4	0.04	68.47	7.825	586.87	195.62
2.1.5	0.05	60.76	8.680	434.02	173.61	3.1.5	0.05	58.87	8.410	504.61	168.20
2.1.6	0.06	53.08	9.100	379.17	151.67	3.1.6	0.06	51.63	8.851	442.57	147.52
W/C = 0.40 S/C = 2.5						W/C = 0.40 S/C = 3					
2.2.2	0.02	120.84	6.042	755.28	302.11	3.2.2	0.02	114.44	5.722	858.31	286.10
2.2.3	0.03	96.54	7.240	603.37	241.35	3.2.3	0.03	92.41	6.931	693.07	231.02
2.2.4	0.04	80.37	8.037	502.34	200.94	3.2.4	0.04	77.49	7.749	581.18	193.73
2.2.5	0.05	68.85	8.606	430.29	172.12	3.2.5	0.05	66.72	8.340	500.40	166.80
2.2.6	0.06	60.21	9.032	376.31	150.53	3.2.6	0.06	58.58	8.787	439.33	146.44
W/C = 0.45 S/C = 2.5						W/C = 0.45 S/C = 3					
2.3.2	0.02	133.93	5.952	744.04	297.61	3.3.2	0.02	127.29	5.689	845.85	281.94
2.3.3	0.03	107.31	7.154	596.18	238.47	3.3.3	0.03	103.02	6.850	684.97	228.32
2.3.4	0.04	89.52	7.957	497.34	198.94	3.3.4	0.04	86.51	7.673	575.49	191.84
2.3.5	0.05	76.79	8.532	426.62	170.65	3.3.5	0.05	74.57	8.270	496.19	165.4
2.3.6	0.06	67.23	8.964	373.50	149.40	3.3.6	0.06	65.53	8.723	436.09	145.36

Mix No.	P/C	Water kg/m³	Polystyrene kg/m³	Sand kg/m³	Cement kg/m³	Mix No.	P/C	Water kg/m³	Polystyrene kg/m³	Sand kg/m³	Cement kg/m³
W/C = 0.35 S/C = 3.5						W/C = 0.35 S/C = 4					
4.1.2	0.02	96.41	5.509	964.08	275.45	5.1.2	0.02	91.73	5.242	1048.33	262.08
4.1.3	0.03	78.41	6.721	784.09	224.03	5.1.3	0.03	75.29	6.453	860.41	215.10
4.1.4	0.04	66.07	7.551	660.74	188.78	5.1.4	0.04	63.842	7.296	729.62	182.41
4.1.5	0.05	57.09	8.156	570.92	163.12	5.1.5	0.05	55.42	7.917	633.35	158.34
4.1.6	0.06	50.26	8.616	502.60	143.60	5.1.6	0.06	48.95	8.393	559.52	139.88
W/C = 0.40 S/C = 3.5						W/C = 0.40 S/C = 4					
4.2.2	0.02	108.683	5.434	1553.25	271.71	5.2.2	0.02	103.48	5.174	1034.77	258.69
4.2.3	0.03	88.618	6.646	1248.75	221.55	5.2.3	0.03	85.13	6.384	851.26	212.81
4.2.4	0.04	74.807	7.481	1178.00	187.02	5.2.4	0.04	72.30	7.230	723.03	180.76
4.2.5	0.05	64.720	8.090	1071.00	161.80	5.2.5	0.05	62.84	7.855	628.38	157.09
4.2.6	0.06	57.031	8.555	1087.75	142.58	5.2.6	0.06	55.57	8.335	555.64	138.91
W/C = 0.45 S/C = 3.5						W/C = 0.40 S/C = 4					
4.3.2	0.02	120.630	5.361	938.231	268.066	5.3.2	0.02	114.93	5.108	1024.55	255.39
4.3.3	0.03	98.603	6.574	766.912	219.118	5.3.3	0.03	94.76	6.317	842.29	210.57
4.3.4	0.04	83.378	7.411	648.498	185.285	5.3.4	0.04	80.61	7.166	716.55	179.14
4.3.5	0.05	72.226	8.025	561.760	160.503	5.3.5	0.05	70.14	7.793	623.48	155.87
4.3.6	0.06	63.705	8.494	495.487	141.568	5.3.6	0.06	62.08	8.277	551.81	137.95

Materials

Cement: It is a Portland cement per specification ASTM C 150 [14].

Sand: It is the locally available sand from Zliten area - Libya. The sieve analysis was carried out and the results showed that it was within the permissible limits according to BS882: 1992 [15] as shown in Table 2.

Table 2: Sieve analysis of Sand

Sieve size (mm)	Cumulative passing (%)	BS882:1992
2.36	85.50	80-100
1.18	73.05	70-100
600 μm	63.00	55-100
300 μm	25.00	5-70
150 μm	0.40	0-15

Polystyrene: It is a lightweight material that is easy to carry and transport with a white color in the form of small beads with a density ranging between (10-27) kg/m³. The density of polystyrene used was 22.4 kg/m³ and Fig.1 shows a sample from polystyrene beads used.

Mixing and curing water: Drinking water was used free of organic matter, salts and impurities.

Figure 1: Polystyrene beads

Mixing, Casting and testing of concrete specimens

Sand and cement were placed in the mixing bowl, and they were mixed manually in dry condition until the mix became homogeneous. Then the polystyrene was added with continuous mixing, and with gradual addition of water. The mixing was done manually to ensure that the polystyrene beads do not fly out. For compressive strength and dry density tests, (100 x 100 x 100) mm cubes were used. After completion of concrete pouring in the cubes as shown in Fig 2, the concrete surfaces were leveled and left for 24 hours to harden, then the molds were dismantled and the concrete cubes were curried in water tank for 28 days, as shown in Figs 3. Compressive strength test has been done as per B.S.1881, Part 116, 1989 [16] as shown in Figs. (4). Dry density test has been done as per ASTM C 642 [17].

Figure 2: Casting of concrete

Figure 3: Curing of concrete

RESULTS AND DISCUSSION

Test results of both compressive strength and dry density for specimens cast with different ratios and after the curing period 28 days were determined and are presented in Table 3 as well as in Figures 5 to 8.

Figure 4: Compression test device during the test

Table 3: Tests results polystyrene lightweight concrete

Mix No.	P/C	Compressive Strength Mpa	Reduction in Compressive Strength	Dry Density Kg/m³	Reduction in Density (%)	Mix No.	P/C	Compressive Strength Mpa	Reduction in Compressive Strength	Dry Density Kg/m³	Reduction in Density (%)
W/C = 0.35 S/C = 2.5						W/C = 0.35 S/C = 3					
2.1.2	0.02	4.35		1287.8	0	3.1.2	0.02	3.13	0	1450.3	0
2.1.3	0.03	2.08	52.18	1081.0	16.06	3.1.3	0.03	1.74	44.41	1293.0	10.84
2.1.4	0.04	1.35	68.97	900.5	30.07	3.1.4	0.04	1.21	61.34	1073.0	26.02
2.1.5	0.05	0.82	81.15	853.3	33.74	3.1.5	0.05	0.63	79.87	966.0	33.39
2.1.6	0.06	0.59	86.44	777.0	39.94	3.1.6	0.06	0.55	82.43	934.8	35.54
W/C = 0.40 S/C = 2.5						W/C = 0.40 S/C = 3					
2.2.2	0.02	4.95	0	1472.0	0	3.2.2	0.02	3.67	0	1414.5	0
2.2.3	0.03	2.62	47.07	1189.0	19.23	3.2.3	0.03	1.51	58.86	1229.0	13.11
2.2.4	0.04	1.78	64.04	1014.3	31.09	3.2.4	0.04	0.88	76.02	1124.8	20.48
2.2.5	0.05	0.93	81.21	940.0	36.14	3.2.5	0.05	0.67	81.74	935.8	33.84
2.2.6	0.06	0.58	88.08	792.3	46.18	3.2.6	0.06	0.38	89.16	847.5	40.08
W/C = 0.45 S/C = 2.5						W/C = 0.45 S/C = 3					
2.3.2	0.02	5.93	0	1462.3	0	3.2.2	0.02	2.35	0	1390.5	0
2.3.3	0.03	2.94	50.42	1212.3	17.10	3.2.3	0.03	2.32	1.28	1212.0	12.84
2.3.4	0.04	2.51	57.67	1117.8	23.54	3.2.4	0.04	1.15	51.06	1102.8	20.71
2.3.5	0.05	1.39	76.56	912.5	37.60	3.2.5	0.05	0.53	77.45	905.8	34.86
2.3.6	0.06	0.65	89.04	913.5	37.52	3.2.6	0.06	0.38	83.83	827.5	40.49

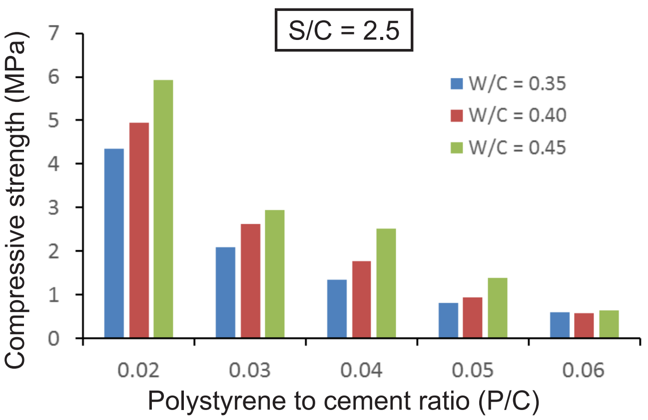
Mix No.	P/C	Compressive Strength Mpa	Reduction in Compressive Strength	Dry Density Kg/m³	Reduction in Density (%)	Mix No.	P/C	Compressive Strength Mpa	Reduction in Compressive Strength	Dry Density Kg/m³	Reduction in Density (%)
W/C = 0.35 S/C = 3.5						W/C = 0.35 S/C = 4					
4.1.2	0.02	3.35	0	1538.0	0	5.1.2	0.02	1.30	0	1461.5	0
4.1.3	0.03	1.53	54.32	1372.5	10.76	5.1.3	0.03	0.88	32.31	1262.3	13.63
4.1.4	0.04	0.98	70.75	1179.0	23.34	5.1.4	0.04	0.61	53.08	1161.8	20.52
4.1.5	0.05	0.52	84.48	1099.0	28.54	5.1.5	0.05	0.54	58.45	1080.5	26.07
4.1.6	0.06	0.42	87.46	980.8	36.22	5.1.6	0.06	0.33	74.62	941.5	35.58
W/C = 0.40 S/C = 3.5						W/C = 0.40 S/C = 4					
4.2.2	0.02	2.67	0	1553.3	0	5.2.2	0.02	1.54	0	1419.5	0
4.2.3	0.03	1.73	35.21	1248.8	19.60	5.2.3	0.03	1.23	20.13	1311.3	7.62
4.2.4	0.04	1.17	56.18	1178.0	24.16	5.2.4	0.04	0.86	44.16	1161.0	18.21
4.2.5	0.05	0.74	72.28	1071.0	31.05	5.2.5	0.05	0.78	49.35	1092.8	23.02
4.2.6	0.06	0.49	81.65	1087.8	29.97	5.2.6	0.06	0.44	71.43	1038.0	26.88
W/C = 0.45 S/C = 3.5						W/C = 0.45 S/C = 4					
4.3.2	0.02	2.49	0	1519.0	0	5.3.2	0.02	1.85	0	1509.5	0
4.3.3	0.03	1.93	22.49	1296.3	14.66	5.3.3	0.03	1.26	31.89	1323.0	12.36
4.3.4	0.04	1.14	54.22	1149.3	24.34	5.3.4	0.04	0.97	47.57	1220.0	19.18
4.3.5	0.05	0.84	66.27	1076.3	29.14	5.3.5	0.05	0.53	71.35	1082.5	28.29
4.3.6	0.06	0.69	72.29	1090.5	28.21	5.3.6	0.06	0.51	72.43	972.3	35.59

Compressive strength

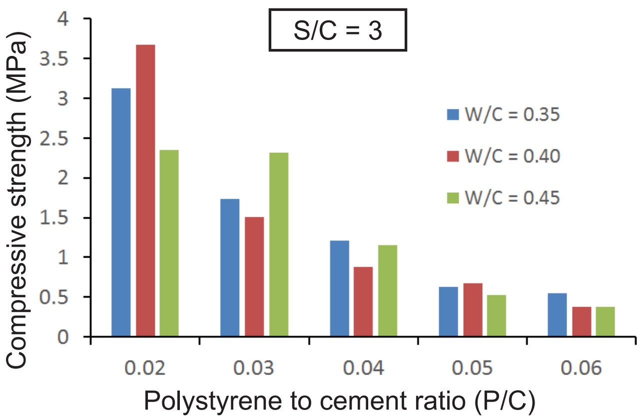
Figs 5 and 6 represent the relationship between compressive strength and polystyrene content for different (S/C) ratio, and (W/C) ratio. The compressive strength decreases as the (P/C) ratio increases. For all mixes the maximum decrease occurred when the (P/C) ratio was increased from 0.02 to 0.03, with average reduction of 37.55%. While, when the (P/C) ratio was increased from 0.03 to 0.04, from 0.04 to 0.05 and from 0.05 to 0.06, the average reduction was 21.21%, 14.59% and 8.19%, respectively. Also it was found that compressive strength is more sensitive to the polystyrene content than dry density as the reduction in compressive strength reached about 82% in comparison with 36% for dry density when the (P/C) ratio was increased from 0.02 to 0.06. This may be attributed to the weak bond between polystyrene beads and cement paste, and the weakness of the bead themselves.

Compressive strength decreases as the (S/C) ratio increases for specified (W/C) and (P/C) ratios in the mixture. As an example, for (W/C) ratio equal to 0.35, the increase of (S/C) ratio from 2.5 to 3 resulted in reductions of 28.05%, 16.34%, 10.37%, 23.17%, and 6.78% for (P/C) ratios 0.02, 0.03, 0.04, 0.05 and 0.06, respectively, and the increase of (S/A) ratio from 3 to 3.5 caused reductions of -7.03% (increasing), 12.07%, 19.00%, 17.46%, and 23.63% for (P/C) ratios 0.02, 0.03 and 0.04 0.05 and 0.06, respectively, while the change of (S/C) ratio from 3.5 to 4, resulted in reductions of 61.19%, 42.48%, 37.76%, - 3.80%, and 21.43% for (P/C) ratios 0.02, 0.03, 0.04 0.05 and 0.06, respectively.

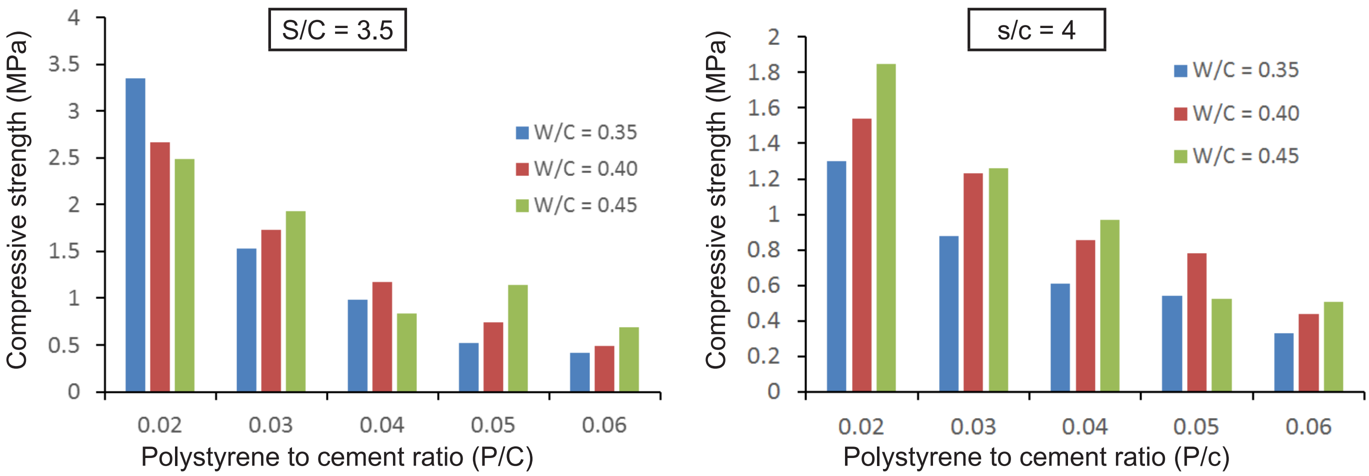
A considerable number of mixes showed an increase in the compressive strength when the (W/C) ratio was increased in addition the obtained maximum measured value of was at (W/C) ratio equal to 0.45. This may be attributed to the good compaction achieved in this mixture.



(a)



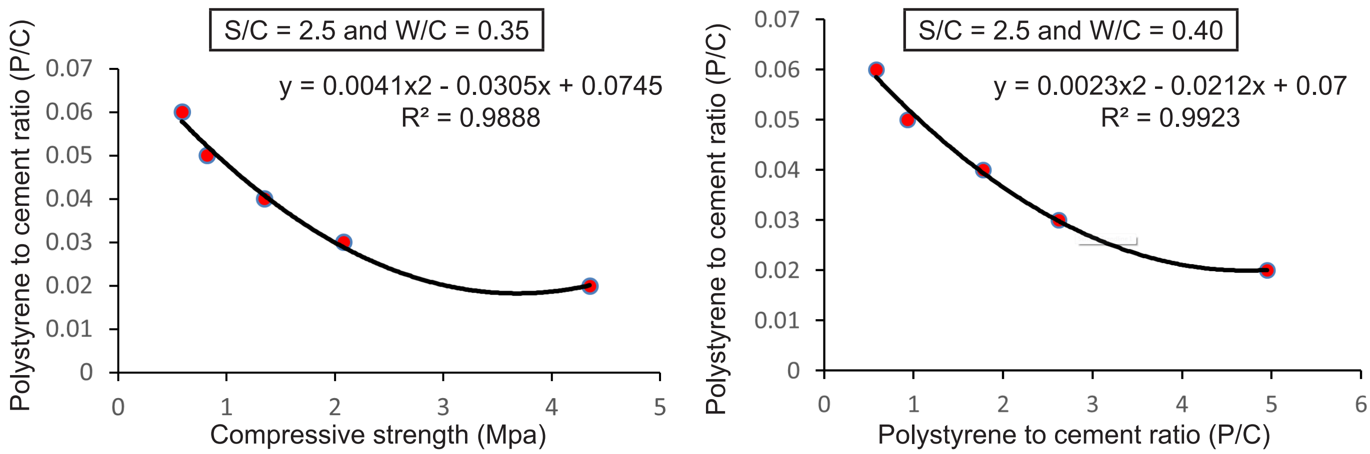
(b)



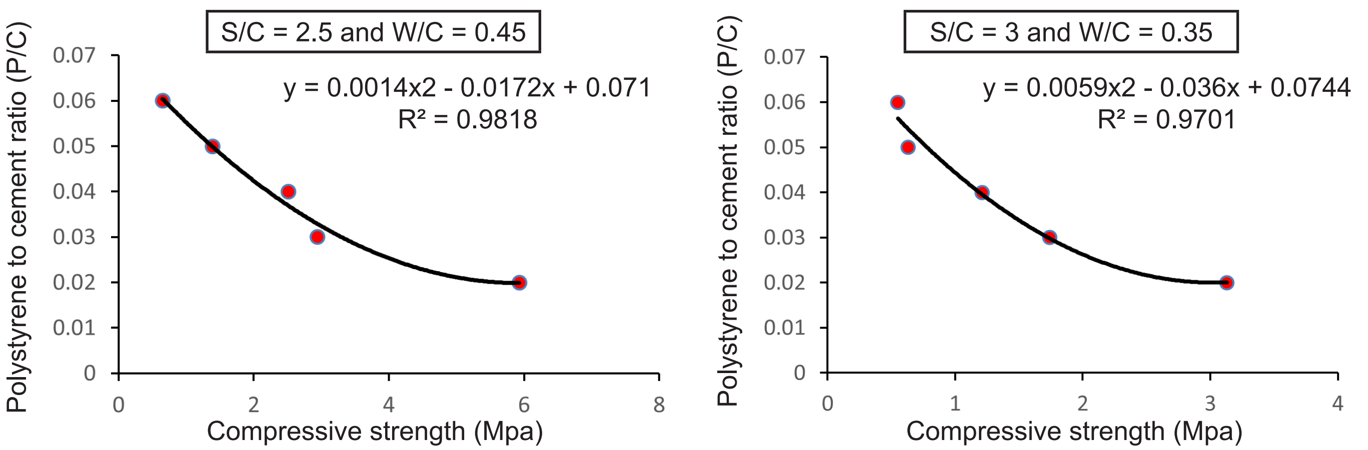
(c) *(d)*

Figure 5: Variation of compressive strength with (P/C), (S/C), and (W/C)

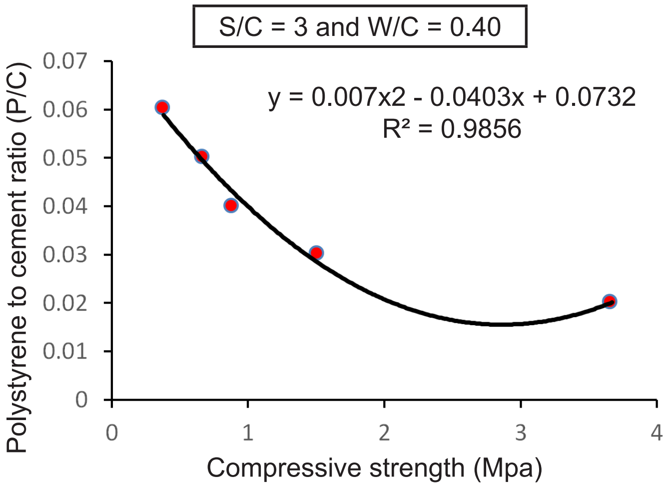
Fig. 6 shows the correlation between compressive strength and polystyrene to cement ratio for mixtures with different (S/C) and (W/C) ratios. Considerably high relationships were obtained between compressive strength and (P/C) ratio as the regression analysis provided an average correlation coefficient (R2) of 0.9751, so, they can be of use in determining mix proportions of polystyrene lightweight concrete based on the required compressive strength.



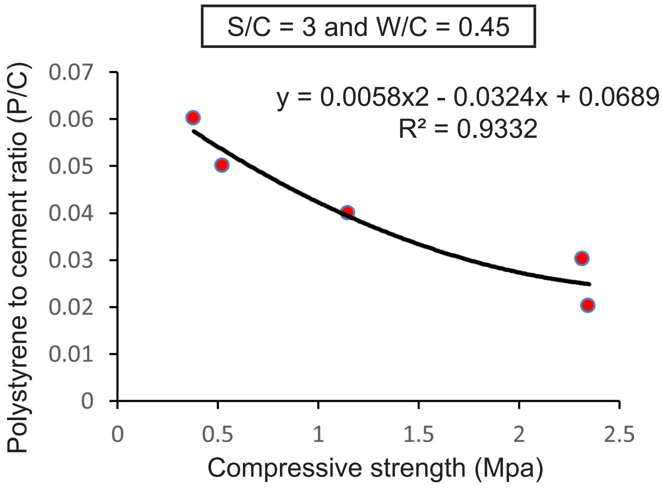
(a) *(b)*



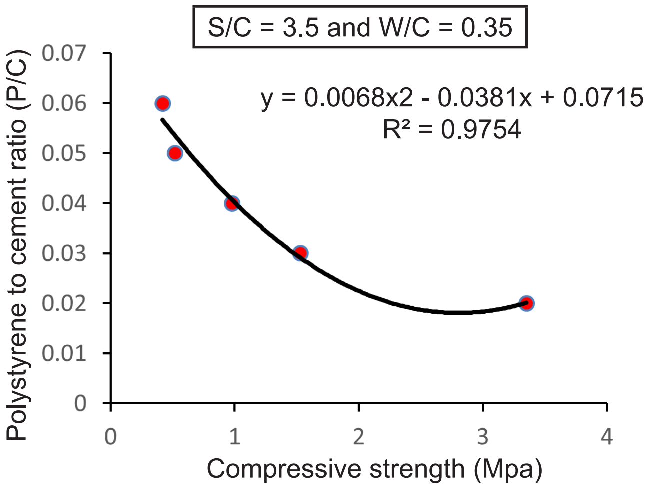
(c) *(d)*


S/C = 3 and W/C = 0.40
y = 0.007x2 - 0.0403x + 0.0732
R² = 0.9856
Polystyrene to cement ratio (P/C)
Compressive strength (Mpa)
0
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0
1
2
3
4

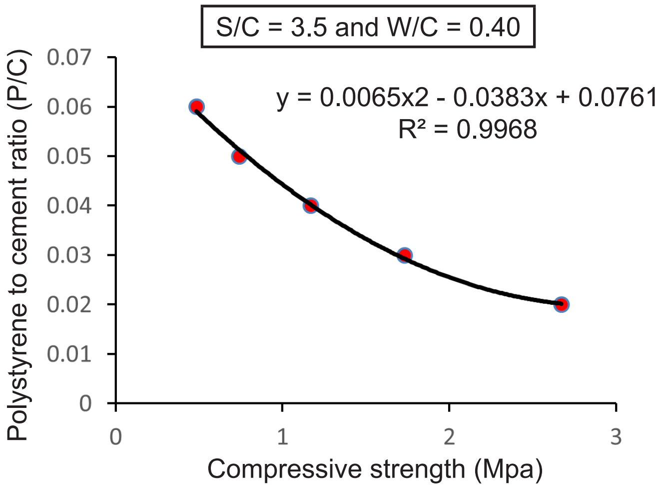
(e)


S/C = 3 and W/C = 0.45
y = 0.0058x2 - 0.0324x + 0.0689
R² = 0.9332
Polystyrene to cement ratio (P/C)
Compressive strength (Mpa)
0
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0
0.5
1
1.5
2
2.5

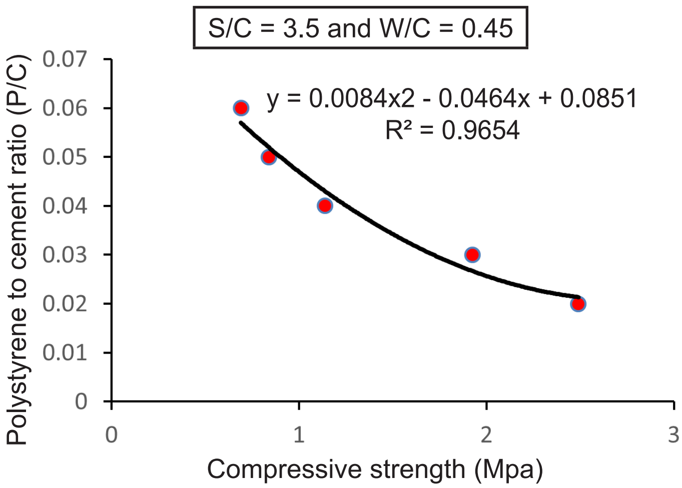
(f)


S/C = 3.5 and W/C = 0.35
y = 0.0068x2 - 0.0381x + 0.0715
R² = 0.9754
Polystyrene to cement ratio (P/C)
Compressive strength (Mpa)
0
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0
1
2
3
4

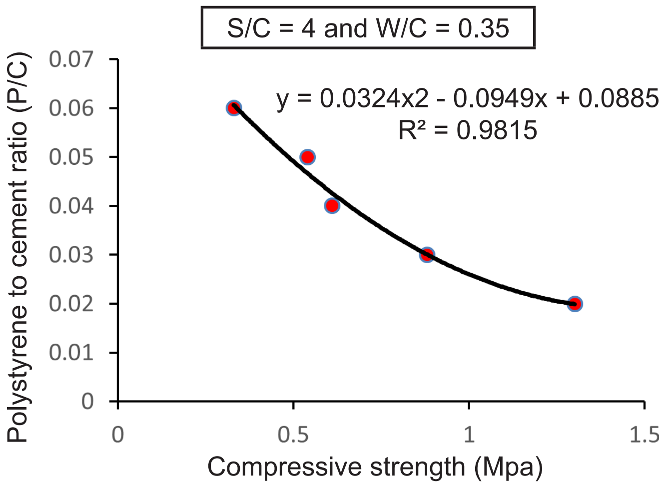
(g)


S/C = 3.5 and W/C = 0.40
y = 0.0065x2 - 0.0383x + 0.0761
R² = 0.9968
Polystyrene to cement ratio (P/C)
Compressive strength (Mpa)
0
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0
1
2
3

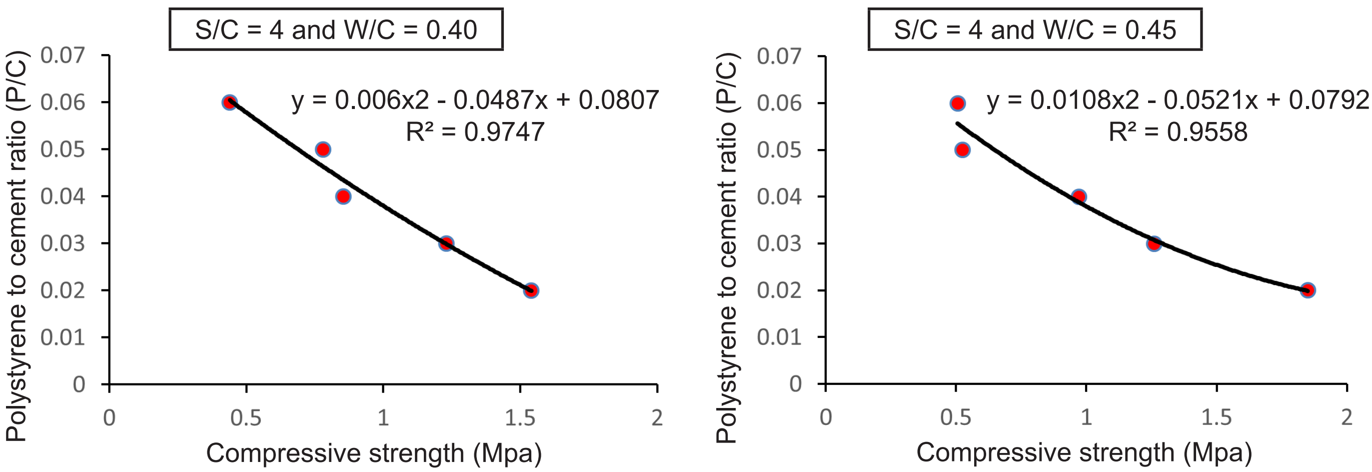
(h)


S/C = 3.5 and W/C = 0.45
y = 0.0084x2 - 0.0464x + 0.0851
R² = 0.9654
Polystyrene to cement ratio (P/C)
Compressive strength (Mpa)
0
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0
1
2
3

(i)


S/C = 4 and W/C = 0.35
y = 0.0324x2 - 0.0949x + 0.0885
R² = 0.9815
Polystyrene to cement ratio (P/C)
Compressive strength (Mpa)
0
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0
0.5
1
1.5

(j)



(k) *(l)*

Figure 6: The relationships between compressive strength and (P/C) ratios

Dry density

Fig 7 and 8 show the relationship between dry density and polystyrene content for different (S/C) and (W/c) ratios. The results presented in diagrams in Figure 7 and Table 3 show the expected increasing and decreasing trends for dry density with the increase of (S/C) ratio and the decrease of (P/C) ratio in the mixture, respectively. The density of the concrete depends upon mix proportions, compaction and curing conditions. For the tested mixtures, the results show that dry density values are ranging from 777.0 kg/m^3 to 1553.3 kg/m^3 and the reduction values in the dry density due the variation of mix proportions are ranging from 7.62% to 46.18%.

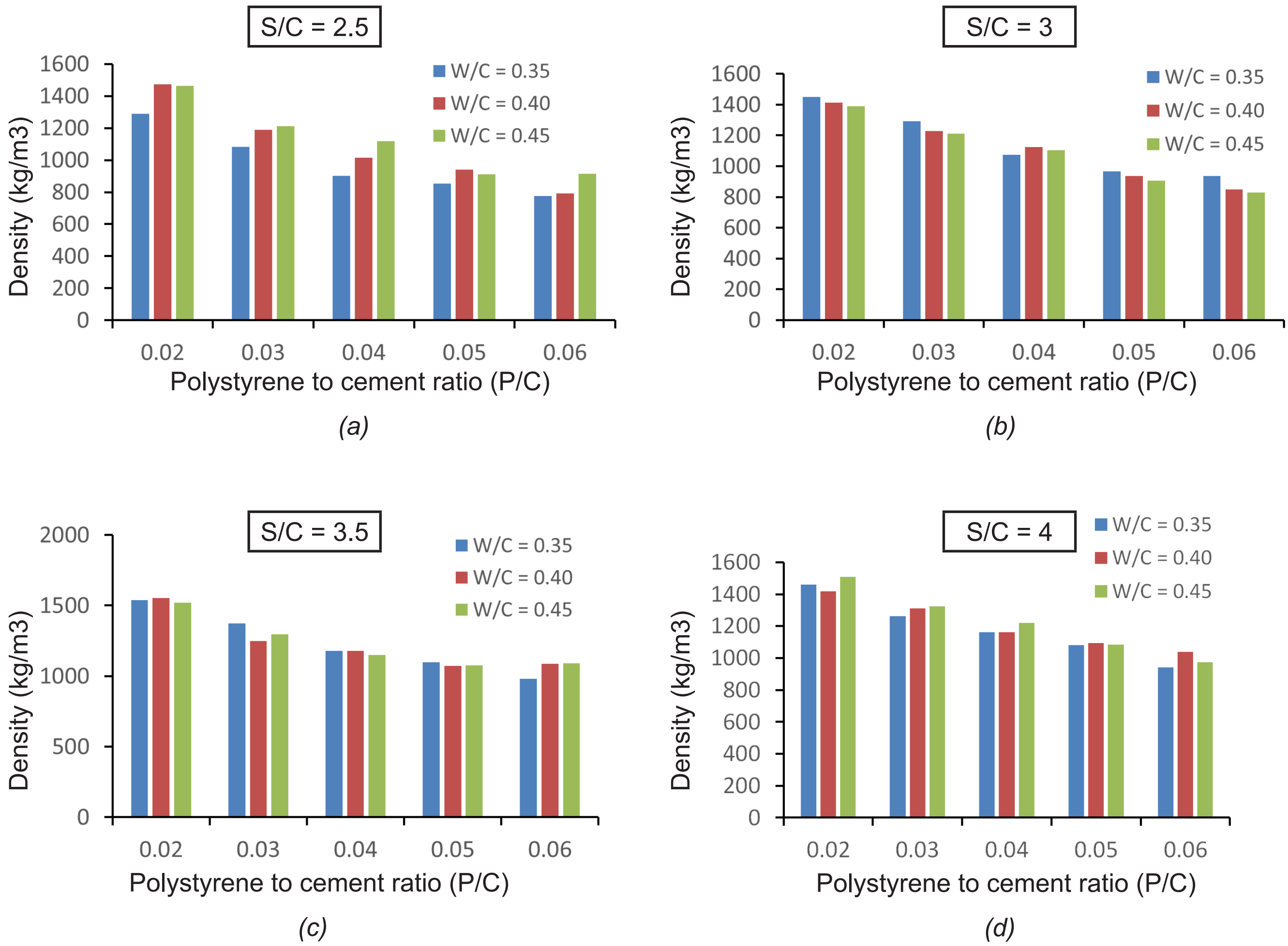
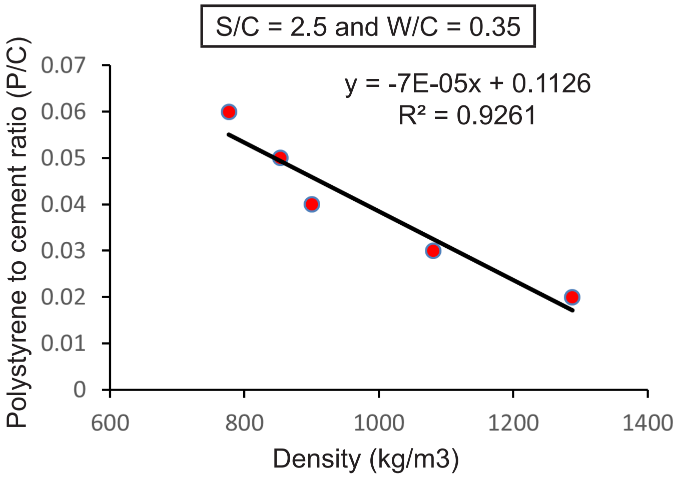
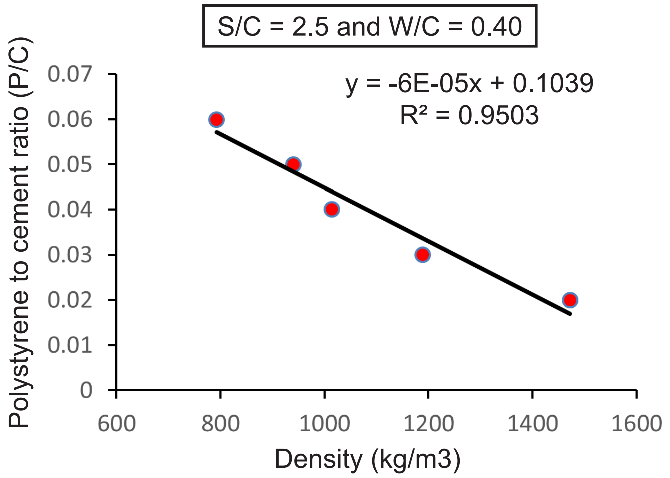


Figure 7: Variation of density with (P/C), (W/C), and (S/C)

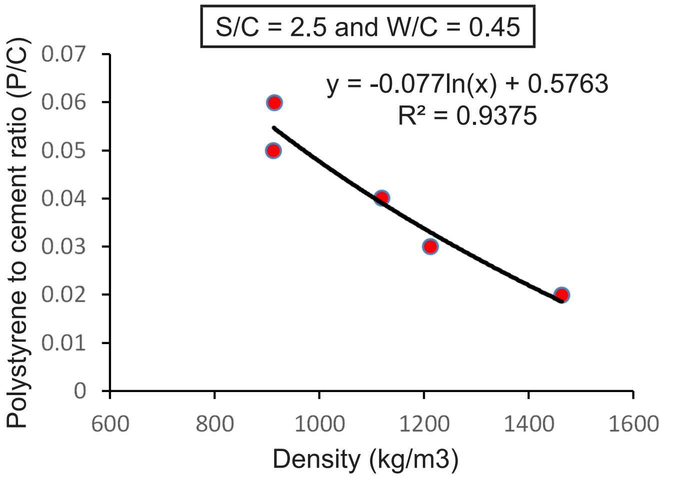
Fig. 8 shows the correlation between dry density and polystyrene to cement ratio for mixtures with different sand and water contents. A Considerably high relationships were obtained between dry densities and (P/C) ratio for polystyrene lightweight concrete as the regression analysis provided an average correlation coefficient (R^2) of 0.9401. So, they can be used to determine the proportion of the mixture components based on the required dry density.



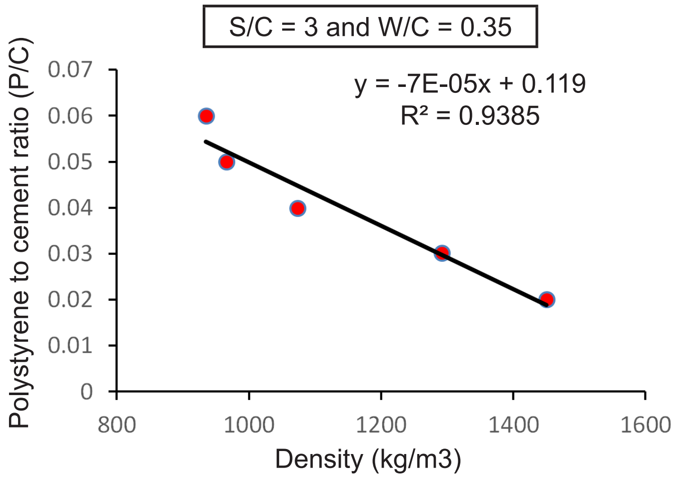
(a)



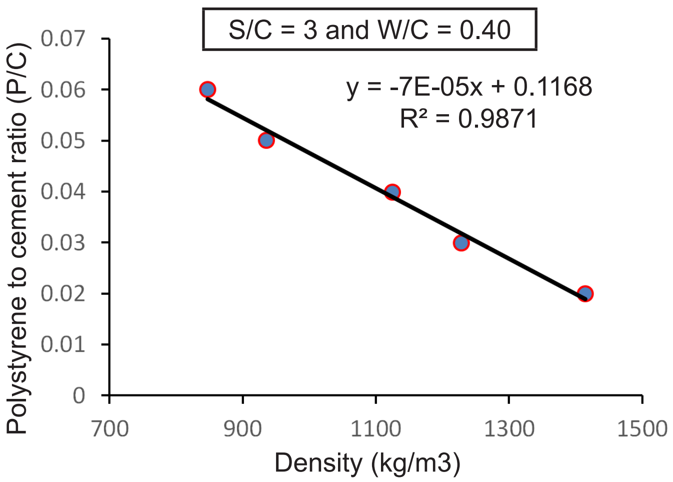
(b)



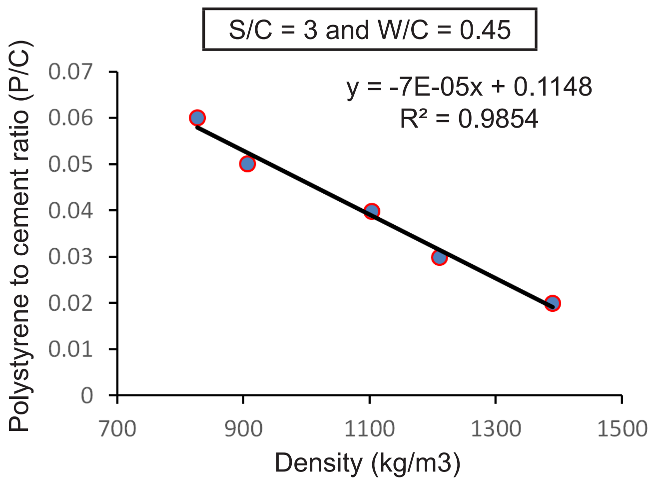
(c)



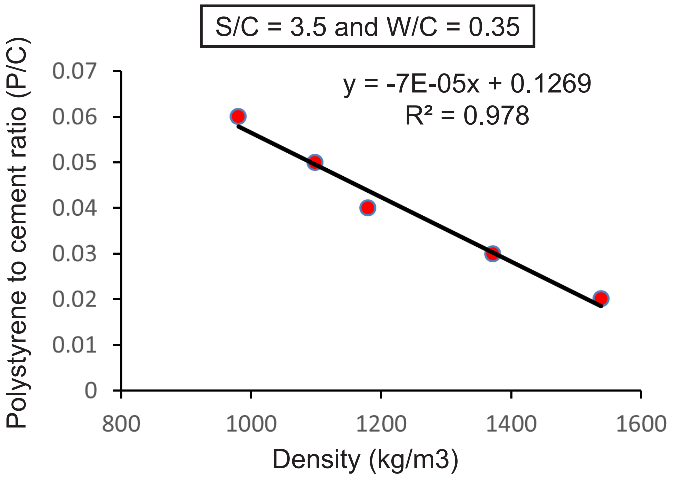
(d)



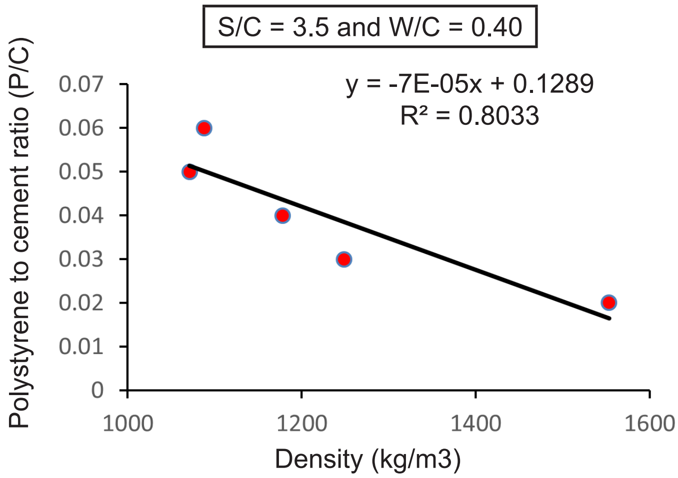
(e)



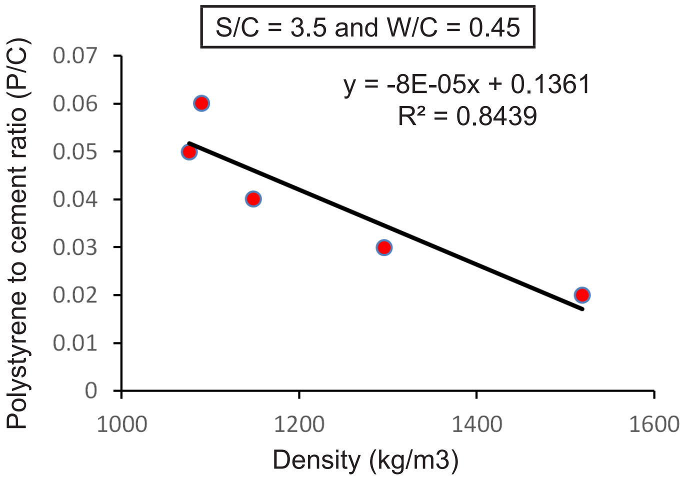
(f)



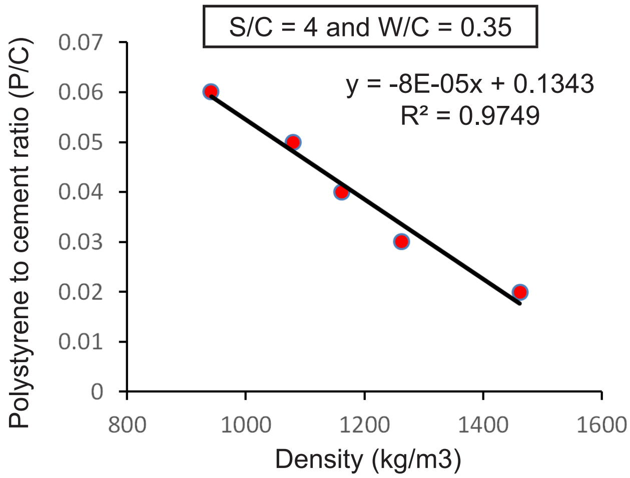
(g)



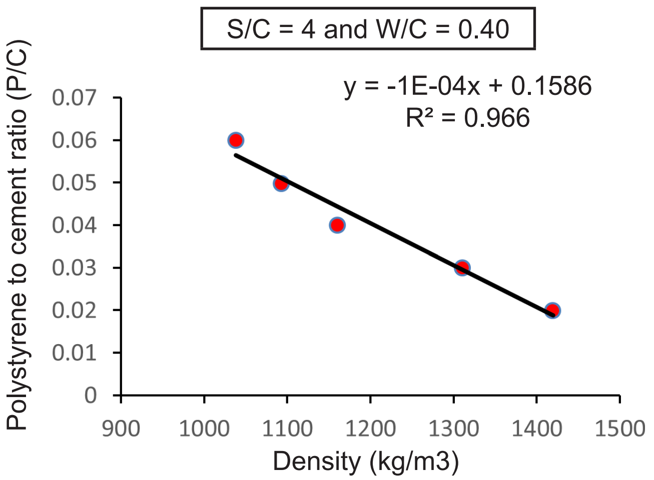
(h)



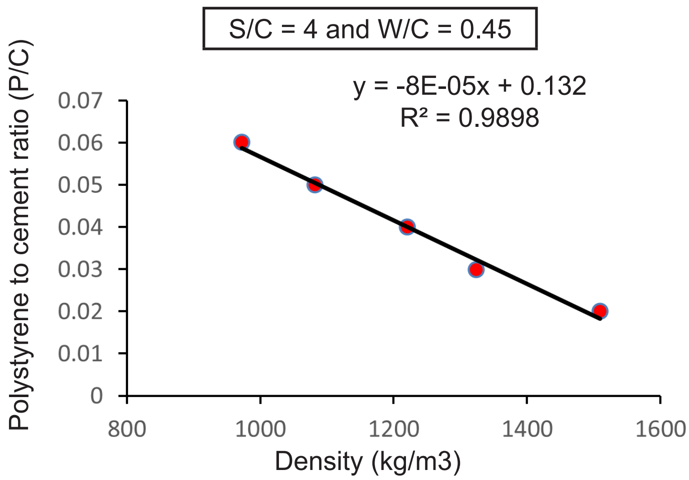
(i)



(j)



(k)



(l)

Figure 8: the relationships between dry density and (P/C) ratios

CONCLUSIONS

This paper shows test results of polystyrene lightweight concrete having different density, compressive strength and mix proportions. Some conclusions can be drawn as follows:

1. The compressive strength decreases as the (P/C) ratio increases. For all mixes the maximum decrease occurred when the (P/C) ratio was increased from 0.02 to 0.03.

2. Compressive strength is more sensitive to the polystyrene content than dry density as the reduction in compressive strength reached about 82% in comparison with 36% for dry density when the (P/C) ratio was increased from 0.02 to 0.06.
3. Some mixtures showed an increase in the compressive strength as the (W/C) ratio was increased and this may be attributed to the good compaction achieved in these mixes.
4. Considerably high relationships were obtained between compressive strength and (P/C) ratio as the regression analysis provided an average correlation coefficient (R^2) of 0.9751, so, they can be of use in determining mix proportions of polystyrene lightweight concrete based on the required compressive strength.
5. Dry density increases with the increase of (S/C) ratio and decreases of (P/C) ratio in the mixture. A consideable decrease in the dry density values was observed as the (P/C) ratio in the mixture was increased from 0.02 to 0.06.
6. A Considerably high relationships were obtained between dry densities and (P/C) ratio of the polystyrene lightweight concrete as the regression analysis provided an average correlation coefficient (R^2) of 0.9401, so, they can be of use to determine the proportion of the mixtures based on the required dry density.

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