Study of some Properties of Lightwigth Concrete Using Polystrene Wastes

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Abstract:

This paper is devoted to study the properties of light weight concrete manufactured from polystyrene, cement, sand and water and that has good strength and thermal insulation and low density compared to other types of light weight concrete which is used as a concrete fill (blinding) or used for non structural concrete members. Seventy two (72) concrete mixs were produced for this study, the three variables are the ratio of cement to sand, the water to cement and the ratio of polystyrene to cement, this is done by changing one of these variables and fixing the other two, these three are cement: sand (C: S = 1:1.5, 1:2, 1:3), water: cement (W/C = 0.30, 0.40, 0.45) and Polystyrene to cement ratio (P/C = 0%, 2%, 3%, 4%, 5%, 6%)

The test results of the concrete cubes (288 cubes) shows that the compressive strength ranged between 0.33-6.53 MPa while the density ranged between 775-2118 kg/m^3, From these results a mathematical relation was established for easy finding the compressive strength and the density of lightweight concrete, this relation can be used in terms of these variables for any percentage and without any concrete testing.

Keywords-concrete mix; polystyrene; cement; water; sand; compressive strength

Introduction:

Lightweight concrete is considered one of modern alternatives that are consistent with the requirements of the present and of great importance in modern enterprises, it is one of the most notable developments in concrete technology and widely used in the construction works due to its properties that can not provided by traditional concrete, this will make it more economical [1].

The lightweight concrete has a low density that ranges from 200 to 1800 kg/m^3 with good insulation properties which provide the necessary saving in energy consumption for cooling and heating as compared to normal concrete. In addition the lightweight concrete will reduce dead loads of the structure leading to smaller construction members in the building leasing

Expanded polystyrene beads are often used as the basis for packaging material. This leads to a large amount of waste material which is not biodegradable. This material could be granulated and used as a lightweight aggregate for concrete[1].

The polystyrene ranked first-class coatings thermally, and are available in low-cost. It is also frequently found as a waste free of charge, thus the use of polystyrene in the preparation of lightweight concrete will contribute to reducing environmental pollution.

Study of overseas commercial literature, e.g. Building Systems Technology (1992) [2], shows that polystyrene is being used as aggregate in lightweight concrete systems. This lightweight concrete is available as precast panels which can be easily handled, cut with power tools or even hand saws, and erected quickly and simply.

A literature survey found very little research results with regard to polystyrene concrete made from either virgin or recycled expanded polystyrene. Some work has been carried out by Sri Ravindrarajah and Tuck (1993) [3] from the University of Technology, Sydney. They investigated the compressive strength, tensile strength, static modulus of elasticity, ultrasonic pulse velocity, drying shrinkage and chemical resistance of polystyrene concrete with densities of 1300 kg/m^3 and 1400 kg/m^3. They also investigated the inclusion of silica fume in the mixes.

Work was also carried out by the Cement and Concrete Association of New Zealand (C&CA, 1994) [4]. This limited study, which examined the strengths and some drying shrinkages of recycled polystyrene concrete with densities ranging from 700 to 1700 kg/m^3, showed that waste granulated polystyrene can be used to manufacture lightweight concrete with similar strength to polystyrene bead concrete.

The study highlighted difficulties in compaction and finishing of concretes with densities below 1000 kg/m^3.

There are many materials used in the production of light-weight concrete including foam, polyurethane, perlite, stilton, rock wool and mineral wool (rock, glass).

There are other types including lightweight concrete by replacing part of coarse aggregates by the bosidonia sea plant, previous research for civil engineering college of engineering at Sabrata, Zawia university, Libya [5], or by using the polystyrene wastes as a percentage of cement [6].

Several types of lightweight concrete given different names according to its production methods, including aerated light weight concrete, limestone light weight concrete and foam light weight concrete.

Many researches to study polystyrene concrete have been conducted since the late 1950s until modern times, mostly concerned with the study of compressive strength of concrete, fracture criteria and the coefficient of thermal conductivity, These literature can be found notably in the sources [7], [8], [9] and [10].

The focus of this research is to investigate the compressive strength and density of concrete made from polystyrene wastes and to find a mathematical relationship that can relate the different mixing ratios with the properties of concrete namely, the compressive strength and density.

Materials and Experimental Work:

*A. **Materials:***

Cement: Portland cement is used locally manufactured (Lebda-Libya) .

Aggregates: Two types of aggregates were used namely fine sand (Sedielsaih-Libya) and gradient within the specifications of America 1992,

polystyrene: A lightweight and easy to carry and transport, white color into small balls with a density ranging from (10-27) kg/m^3, specific weight 22.4 and gradient ranges from 0.25 mm to 4.75 mm, Fig. 1 illustrates the polystyrene granules used in mixing the lightweight concrete.

Mixing and curing water: Normal drinking water is used free from organic matter, salts and impurities

Fig. 1. **Polystrene granuallers**

*B. **Concrete Mixes:***

Seventy two (72) concrete mixes were produced, 4 cubes with dimensions (100 × 100 × 100 mm) for each mix giving a total of 288 cube for concrete testing, the concrete mixtures contain a different polystyrene to cement ratios by weight (P/C = 0%, 2%, 3%, 4%, 5%, 6%), water to cement (w/c = 0.35, 0.40, 0.45) and cement to sand was (C:S = 1:2.5, 1:3, 1:3.5, 1:4), in these concrete mixes we have changed one of the above ratios of ingredients while retaining the same proportions to conclude the effect of each ratio separately from other ratios. the weight of each material component was established using the following volumetric equation (1):

$$Vc + Vs + Vp + Vw = 1\,m^3 \qquad (1)$$

where: Vc is the volume of cement, and V_P, V_S, V_W are the volume of polystyrene, sand and water respectively, Table 1 describes the weights of materials (cement, sand, polystyrene, water) per cubic meter. the mixes were produced

C. Experemental Programe:

The compressive strength tests were done on the prepared concrete cubes according to British standards (BS4550: Part 3:78) , for each and for each mix four specimens were used, the average reading was taken as the concrete strength for each mix type, the concrete cubes were immerged in water for 28 days for curing before draying for 24 hours and then testing, the concrete density tests were conducted according to British standards (BS 1881: Part 114).

Results and Analysis:

Table 1 shows the average compressive strength and density test results for the different types of mixes, The table also indicates the amount of cement used and the polystyrene ratio for each mix type.

The effect of polystyrene ratios on the compressive strength for the different mixes for water to cement of 0.30 is shown in Fig. 2, a best fit formula for each mix was established, the trend is showing a decrease in strength with increase of polystyrene ratio, the same observation was noticed for water to cement ratios of 0.40 and 0.50 as shown in Fig. 3 and Fig 4. Fig. 5 is a combined results for compressive strength of all water to cement ratios (0.3, 0.4 and 0.5) ratios as well as the mathematical formulae.

The effect of polystyrene ratios on the concrete density for the different mixes For water to cement of 0.30 is shown in Fig. 6, a best fit formula for each mix was established, The trend is showing a decrease in density with the increase of polystyrene ratio, the same observation applies for water to cement ratios of 0.40 and 0.50 as shown in Fig 7 and Fig 8. Fig. 9 is a combined results for concrete density of all water to cement ratios (0.3, 0.4 and 0.5) ratios as well as the mathematical formulae.

The mathematical relation curves for compressive strength and density test results can be easily used to find the mix ratios and accordingly the materials components outside of the range studied in this research.

One of the main observations from this study is that a great reduction in compressive strength beyond 6% polystyrene ratios. The compressive strength of polystyrene lightweight concrete was reduced for many reasons as the polystyrene granules acted like voids in the matrix, the bond between the granules and concrete is weak. With increase of void content of the concrete there will be corresponding decrease in strength. The reduction in strength was also due to the fact that the polystyrene granules is more elastically deformable than the matrix. This will give very week concrete that can be used only in some backfill works, for the structural lightweight concrete made of polystyrene these properties can be modified by using chemical additives such as silica fume.

Table 1 Compressive strength and density test results (28 Days)

Cement sand ratio	(W / C = 0.3) Water cement ratio			
	Polystyrene Ratio P/C	Cement Weight kg/1m^3	Compressive Strength (stress) MPa	Density kg/m^3
C : S 1:1.5	0	852.503	26.16	1980.12
	0.02	460.19	8.67	1093.15
	0.03	374.109	2.75	861.87
	0.04	315.158	1.92	718.19
	0.05	272.256	1.19	655.21
	0.06	239.635	0.7	603.9
	(W / C = 0.4) Water cement ratio			
	0	785.536	27.83	1878.41
	0.02	439.944	6.99	1182.88
	0.03	360.618	4.51	961.87
	0.04	305.529	2.22	816.93
	0.05	265.04	1.71	701.67
	0.06	234.027	0.99	622.47
	(W / C = 0.5) Water cement ratio			

Cement sand ratio	(W / C = 0.3) Water cement ratio			
	Polystyrene Ratio P/C	Cement Weight kg/1m^3	Compressive Strength (stress) MPa	Density kg/m ^{3}
	0	728.324	26.89	1828.22
	0.02	421.405	8.2	1181.64
	0.03	348.066	3.31	972.63
	0.04	296.471	3.09	804.81
	0.05	258.197	2.09	707.54
	0.06	228.675	1.77	612.88
C : S 1:2.0	(W / C = 0.3) Water cement ratio			
	0	736.268	22.43	2030.24
	0.02	424.052	7.12	1205.65
	0.03	349.87	2.33	966.45
	0.04	297.779	1.69	915.32
	0.05	259.188	0.97	763.85
	0.06	229.452	0.63	692.47
	(W / C = 0.4) Water cement ratio			
	0	685.776	24.65	1933.09
	0.02	406.802	5.67	1297.55
	0.03	338.043	3.67	1060.4
	0.04	289.168	1.73	912.38
	0.05	252.64	1.33	771.16
	0.06	224.306	0.74	700.98
	(W / C = 0.5) Water cement ratio			
	0	641.766	24.26	1905.81
	0.02	390.9	7.66	1228.9
	0.03	326.99	3.05	1070.05
	0.04	281.041	2.81	908.49
	0.05	246.415	1.71	799.73
	0.06	219.385	1.24	700.12
C : S 1:2.5	(W / C = 0.3) Water cement ratio			
	0	647.926	18.99	1930
	0.02	393.177	4.92	1472
	0.03	328.581	1.91	1189
	0.04	282.216	1.37	1014.25
	0.05	247.317	0.76	940.75
	0.06	220.1	0.55	792.25
	(W / C = 0.4) Water cement ratio			

Cement sand ratio	(W / C = 0.3) Water cement ratio			
	Polystyrene Ratio P/C	Cement Weight kg/1m³	Compressive Strength (stress) MPa	Density kg/m ³
	0	608.5	22.84	1993.25
	0.02	378.303	4.95	1262.25
	0.03	318.128	2.62	1112.25
	0.04	274.47	1.35	997.75
	0.05	241.348	0.93	962.5
	0.06	215.36	0.58	
	(W / C = 0.5) Water cement ratio			
	0	573.596	23.11	1993.25
	0.02	364.513	7.01	1262.25
	0.03	308.32	2.75	1112.25
	0.04	267.138	2.76	997.75
	0.05	235.661	1.56	962.5
	0.06	210.82	0.98	776.5
C : S 1:3.0	(W / C = 0.3) Water cement ratio			
	0	578.512	10.28	2084.81
	0.02	366.492	2.85	1370.65
	0.03	309.734	1.56	1143.61
	0.04	268.199	1.04	981.05
	0.05	236.486	0.51	922.78
	0.06	211.48	0.49	844.41
	(W / C = 0.4) Water cement ratio			
	0	546.875	14.63	2054.5
	0.02	353.535	3.67	1414.5
	0.03	300.429	1.51	1229
	0.04	261.194	0.88	1124.75
	0.05	231.023	0.67	935.75
	0.06	207.101	0.38	847.5
	(W / C = 0.5) Water cement ratio			
	0	518.518	10.28	1991.68
	0.02	341.463	2.85	1348.5
	0.03	291.667	1.56	1258.22
	0.04	254.545	1.04	1058.25
	0.05	225.806	0.51	921.5
	0.06	202.899	0.49	830.04

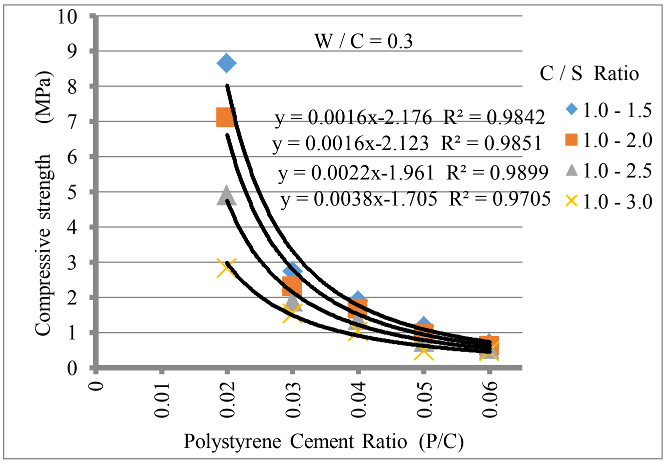

Fig 2. Mathematical relations for compressive strength results for mixing ratios (C/S) of 0.30 water to cement ratio

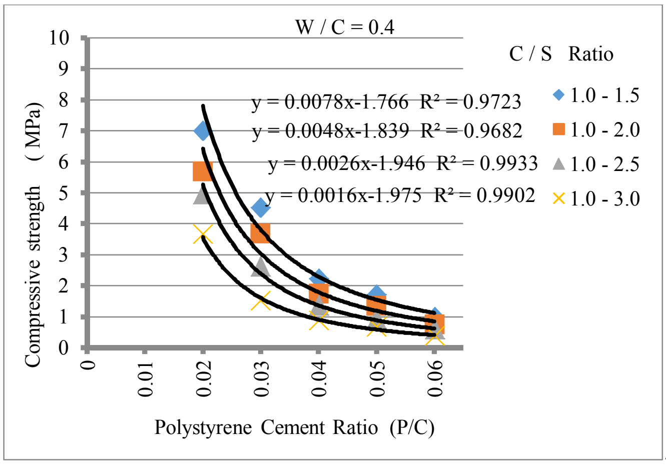

Fig. 3 Mathematical relations for compressive strength results for mixing ratios (C/S) of 0.40 water to cement ratio

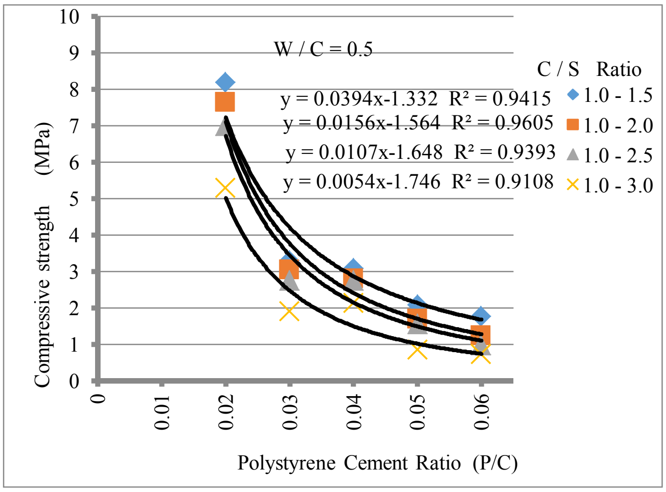

Fig. 4 Mathematical relations for compressive strength results for mixing ratios (C/S) of 0.50 water to cement ratio

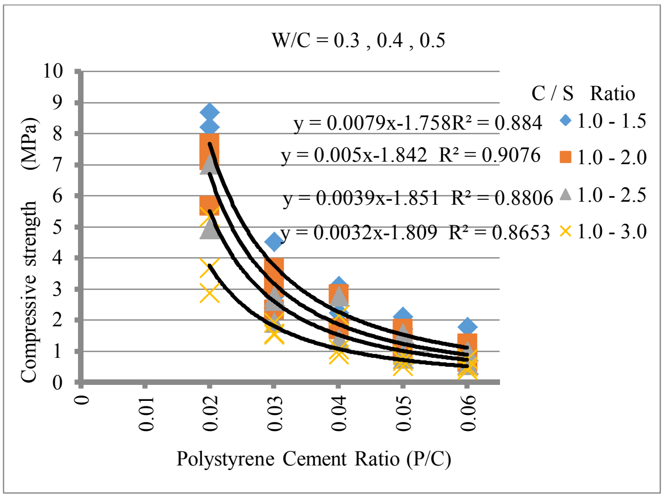

Fig. 5 Mathematical relations for compressive strength results for all mixing ratios (C/S) and water to cement ratios of 0.30, 0.40 and 0.50

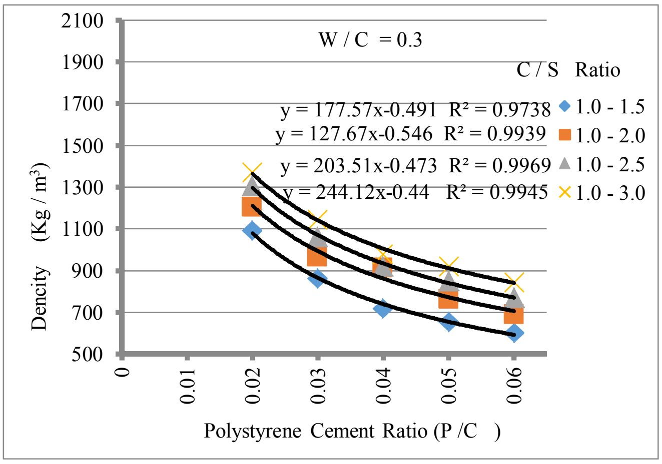

Fig. 6 Mathematical relations for density results for all mixing ratios (C/S) and water to cement ratios of 0.30

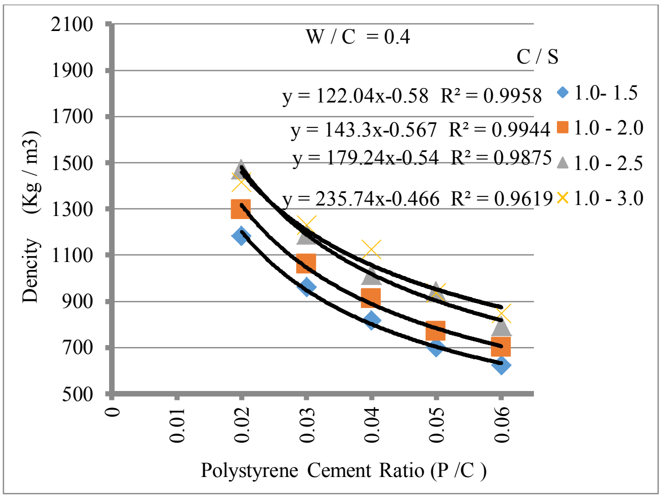

Fig. 7 Mathematical relations for density results for all mixing ratios (C/S) and water to cement ratios of 0.40

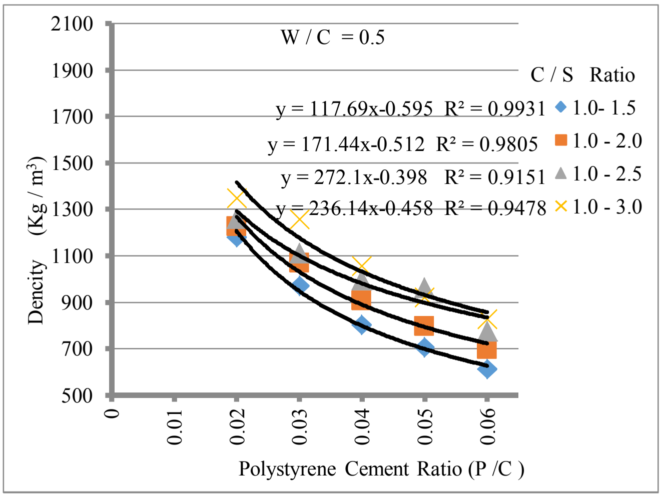

Fig. 8 Mathematical relations for density results for all mixing ratios (C/S) and water to cement ratios of 0.50

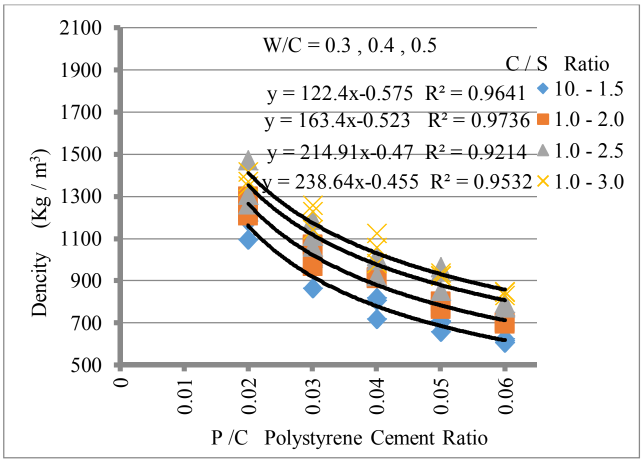

Fig. 9 Mathematical relations for density results for all mixing ratios (C/S) and water to cement ratios of 0.30, 0.40 and 0.50

Conclusions and Recommendations:

Mathematical relation curves for compressive strength and density test results were established that can be used to find the mix ratios

The concrete compressive strength decreases with the polystyrene ratio (P/C) increase.

The concrete density decreases with the polystyrene ratio (P/C) increase.

The largest concrete compressive strength was obtained when using 2% of polystyrene for all C/S ratios.

The largest concrete compressive strength was obtained for the mix ratio of (C/S) 1: 1.5.

The density and compressive strength for the polystyrene concrete was less than the normal concrete the decrease was in the range of 57 to 98 %.

The workability of polystyrene concrete was good despite the low water to cement ratio.

This study proved that there is a great potential for the used polystyrene to be used effectively in concrete. Even though, the compressive strength is decreasing tremendously, there are several properties that can be improved such as the thermal conductivity (recommended future study), this abundant waste materials exists in the environment and can be obtained with no cost. The use of polystyrene in concrete is an excellent choice for attaining sustainability, a cleaner environment, and a reduction in construction cost.

The mathematical relations obtained in this study represent only strength and density of lightweight concrete, More studies to other properties are required in order to have a reliable mathematical relations that can be widely used.

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