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# Effect of cement and EPS beads ratios on compressive strength and density of lightweight concrete

Abdulkadir Kan[a] & Ramazan Demirboğa[b]*

[a]Vocational College of Erzurum, Construction Program, [b]Department of Civil Engineering, Faculty of Engineering, Atatürk University, 25240 Erzurum, Turkey

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The compressive strengths and slump values of concretes made up of mixtures of expanded polystyrene (EPS) beads and cement were investigated. To determine the effect of Portland cement (PC)/EPS ratio, on the compressive strength of EPS concrete, 1/0 (control sample), 1:4, 1:2, 3:4 and 1:1 mix proportion by volume were used. EPS beads content for the mixtures were kept constant at 0.05 $m^3$. The analysis of the test results leads to the conclusion 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.

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The consumption of aggregates of all types has been increasing in recent years in most countries at a rate far exceeding that suggested by the growth rate of their economy or of their construction industries. Available source of natural aggregates may be at a considerable distance from the point of use, in which case the cost of transporting is disadvantage. There are however other factors to be considered. The continued and expanding extraction of natural aggregate is accompanied by serious environmental problems. Often it leads to irremediable deterioration of the countryside. Quarrying of aggregates leads to disturbed surface area. In addition, the demand for lightweight concrete in many applications of modern construction is increasing, owing to the lower density results in a significant benefit in terms of load-bearing elements of smaller cross sections and a corresponding reduction in the size of the foundation.

Lightweight aggregates are broadly classified in to two types-natural (pumice, diatomite and volcanic cinders) and artificial (perlite, expanded shale, clay, slate and sintered pulverized fly ash (PFA). EPS beads are a type of artificial ultra-lightweight (density of less than 30 kg/$m^3$), nonabsorbent aggregate. It can be used to produce low density concretes required for building applications like cladding panels, curtain walls, composite flooring systems, and load-bearing concrete blocks[1].

Lightweight aggregate concrete can be produced by replacing the normal aggregate with lightweight aggregate, either partially or fully, depending upon the requirements of density and strength[2]. EPS beads in granular forms are used as lightweight aggregate to produce lightweight concrete with the density varying from 400 to 2000 kg/$m^3$. The present study covers the use of EPS beads as lightweight aggregate in cement mortars.

One of the fastest growing sectors in the construction industry around the world is insulated concrete forms (ICFs). These forms, which are made of EPS, are used to build reinforced concrete walls for both residential and commercial buildings. Once erected, concrete is poured into the form. After the concrete has hardened, the forms stay in place and become the insulation for the walls.

EPS concrete is a kind of lightweight concrete, which is lighter than normal concrete by mixing beads into cement slurry. There are many studies related to the EPS aggregate concrete; especially Sabaa and Ravindrarajah[3], and Tang[4]. They have been studied, workability assessment and fractal properties for EPS aggregate concretes. Also, the density of concrete significantly affects hardened concrete properties of EPS aggregate concrete and compressive strength is

*For correspondence (E-mail: ramazan@atauni.edu.tr)

more sensitive to the density compared to tensile strength and modulus of elasticity have also been reported by Ravindrarajah and Collins[5]. They concluded that the compressive strength was a function of density of concrete, with an increase of density resulting in higher compressive strength. Demirboga *et al*.[6] reported that lightweight aggregate concrete is more durable than traditional concrete.

Polystyrene is a vinyl polymer, structurally; it is a long hydrocarbon chain, with a phenyl group attached to every other carbon atom. Polystyrene is produced by free radical vinyl polymerization, from the monomer styrene. The styrene content of high-impact polystyrene varies from about 88-97%. Where a blowing (or expanding) agent is added to the polystyrene, the product is referred to as expandable polystyrene. The blowing agent may be added during the polymerization process (as in the production of expandable beads), or afterwards as part of the fabrication process (as in foamed polystyrene applications). Expanded polystyrene (EPS) beads can also be combined with other materials to produce light-weight concrete composites boards for applications such as thermal/sound insulation and displaying/partitioning[7].

The compressive strength of the investigated material depends on its density and the type of granules used. According to the Laukaitis *et al.*[8] suggestion, fine granules allow for the highest composite compressive strength, which is on average by 40% higher than when large granules are used and 68% higher than when crumbled granules are used.

The mechanical strength of EPS beads varies with its density. EPS has a compressive strength between 0.068-0.39 MPa for most construction applications. Within that range EPS can be produced to meet specific strength requirements. The most important mechanical property of EPS insulation and building products is its resistance to compressive stresses, which increases with increase in density.

The aim of this paper is to determine the effect of PC to EPS ratios, 1/0 (control sample), 1:4, 1:2, 3:4 and 1:1 mix proportion by volume on the compressive strength of EPS concrete. EPS beads content for the mixtures were kept constant at 0.05 $m^3$.

## Experimental Procedure

Portland cement (PC) was Type II according to the ASTM C 150 and Turkish standards CEM II-B/32.5R. EPS beads were obtained from the Orcan A.Ş., in Istanbul, Turkey. A type of commercially available spherical EPS beads that is maximum sieve size was 8.0 mm. The grading shows that EPS beads size changed between 3.0-8.0 mm. The bulk density was 10-20 kg/$m^3$. A polycarboxilate based super-plasticizer was used. The workability of fresh polystyrene aggregate concretes was determined at 20°C by the finger-touching method prescribed in Choi and Ohama[9]. The chemical composition and physical properties of the materials used in this study are summarized in Tables 1 and 2.

PC/EPS ratios, 1/0 (control sample), 1:4, 1:2, 3:4 and 1:1 mix proportion by volume were prepared. EPS beads content for the mixtures were kept constant at 0.05 $m^3$. The complete details of the EPS concrete mixes are given in Table 3.

The interfacial zone between cement paste and aggregate plays a critical role in determining mechanical properties of concrete[10]. For this reason, EPS beads were wetted initially with a part of the mixing water and super plasticizer before adding of the remaining materials. The pre-wetting of lightweight aggregate will critically affect the strength and slump of its concrete[11]. A technique similar to cement-wrapping was applied on the EPS beads The concrete mixes were prepared in a laboratory counter-current mixer for a total of 5 min. Precautions were taken to ensure homogeneity and full compaction. The fresh concrete densities and slump values were measured immediately after the mixing. The fresh

Table 1—Physical and mechanical properties of EPS

| Property | Average value |
|---|---|
| Density | 13 kg/$m^3$ |
| Compressive strength | 0.09 MPa |
| Flexural strength | 0.21 MPa |
| Water Vapor permeability | 1.4 Perm-cm |
| Water Absorption | 4 % by vol. |

Table 2—Chemical composition of cement (II-B/32.5R)

| Chemical composition | % |
|---|---|
| Silica ($SiO_2$) | 21.78 |
| Alumina ($Al_2O_3$) | 6.56 |
| Ferric oxide ($Fe_2O_3$) | 4.13 |
| Calcium oxide (CaO) | 46.09 |
| Magnesium oxide (MgO) | 2.08 |
| Sodium oxide ($Na_2O$) | 0.36 |
| Potassium oxide ($K_2O$) | 0.42 |
| Sulphuric anhydride ($SO_3$) | 2.16 |
| Loss on ignition (LOI) | 3.84 |

concrete was then poured into moulds and compacted by hand. For each mixture, three samples of 50×50×50 $mm^3$ prisms were prepared and the specimens were cured two days under wet gunny bags initially and than removed from the molds and cured in lime saturated water up to the date of testing[2].

The specimens were oven dried at the age of 28 days at 60±5°C and weighed at 24 h intervals until the loss in weight did not exceed 1% in a 24 h according to ASTM C 332[12]. Saturated surface dry cubes were kept in a hot air oven at 60°C (although ASTM suggests a temperature range of 110±10°C for traditional concrete) until a constant weight was attained, because at the temperature of 110±10°C, the EPS beads initially shrank and finally evaporated.

At 28 days, samples were tested for compressive strength in accordance with the method proposed by ASTM C 109[13]. Compressive strength test was carried out in a testing machine of 2000 kN capacity at a loading rate of 2.5 kN/s. Each test was repeated three times and the test results were averaged.

## Result and Discussion

Fresh and hardened concrete properties (density and slump) are presented in Figs 1 and 2 respectively. The reduction in workability, as indicated by the reduction in slump values, is increased with increase of PC/EPS ratio in the mixes and it was changed between 8 mm to 43 mm. At a EPS of 1/4 by volume, the average slump decreased near to zero (see Fig. 2) and the mix was not workable such that an extra effort was required for the compaction of the concretes via tamping with a standard 16 mm diameter steel rod. Moreover, the decrease in the slump was more remarkable for low PC/EPS concretes. Figure 2 also shows that the EPS concretes had lower slump than the control sample. Also, this study showed that, precaution must be taken while mixing, pouring and compacting of EPS beads concrete to minimize segregation of the concrete mixture. It was observed that fairly a uniform concrete may be achieved by limiting the duration of vibration to prevent the accumulation of the beads over the form because of their lower densities. In order to achieve a good compaction, it was also observed that it is necessary to add super plasticizer to the concrete mix to improve its workability and prevent the segregation of EPS beads. The EPS beads reduced the workability of the concrete. The highest slump value occurred at control sample. This is may be due to density of PC that is very higher than the density of EPS beads. Similar to the normal weight concrete, the workability of polystyrene aggregate concrete is influenced by the water to cement ratio and water content[3]. Beecrof[14] reported that an equal slump for the lightweight and normal weight concretes would not represent the same degree of workability.

Table 3—Details of EPS concrete mixes

| Mix Type | Cement Weight (kg) | Cement volume ($m^3$) | EPS beads volume ($m^3$) | PC/EPS (by volume) | water + % 0.3 SP** ($l/m^3$) | w/c ratio |
|---|---|---|---|---|---|---|
| 1 | 39 | 0.0125 | 0.05 | 1/4 | 15 | 0.39 |
| 2 | 79 | 0.0250 | 0.05 | 1/2 | 28 | 0.35 |
| 3 | 118 | 0.0375 | 0.05 | 3/4 | 40 | 0.34 |
| 4 | 158 | 0.0500 | 0.05 | 1/1 | 49 | 0.31 |
| 5* | 39 | 0.0125 | - | - | 15 | 0.39 |

*Control sample, ** super plasticizer

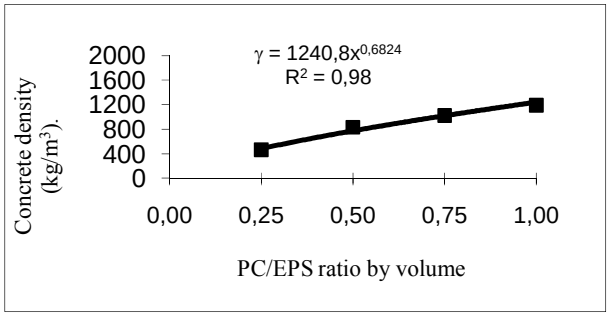



Fig..1 —Effect of EPS volume on the concrete density of EPS concrete.

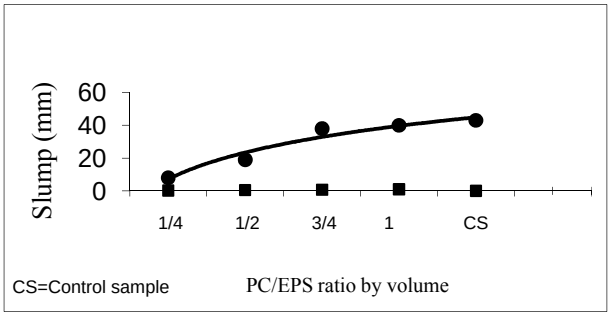



Fig. 2—Variation in the slump of the concretes with EPS

With increase of PC/EPS beads ratio result in an increase of the fresh concrete density as shown in Fig. 1. The density of the hardened concretes ranged from 464 to 1940 kg/m$^3$ depending on the PC contents. The relationship between density and PC/EPS ratio was power and determination coefficient was 0.98.

$$\gamma = 1240.8x^{0.6824} \quad \ldots \quad (1)$$

Where $\gamma$ denotes the density of concrete, kg/m$^3$ and $x$ denotes the PC/EPS ratio.

The 1/4 (PC/EPS) mixes only had enough paste to coat the EPS beads and hold them together. This gave a very porous type of concrete. They were basically lean mixes. Only the 3/4 and 1/1 mix types had enough paste to fill the voids and allow well finished surface to be achieved.

It can be seen from Table 4 that the density of concrete increases with an increase in cement volume (keeping the EPS volume). The reason for this is that the specific gravity of PC is higher than that of EPS beads. Experiments showed that by mixing 1/4, 1/2, 3/4, and 1/1 of the PC/EPS ratio by volume, the density of hardened concrete reduced 76, 57, 47, and 39%, respectively, when compare to the control sample. Ravindrajah[15] indicated that by replacing 10%, 20%, 30% of the coarse aggregate by solid volume with polystyrene beads, the density of concrete reduces from 2455 kg/m$^3$ to 2330, 2210 and 2080 kg/m$^3$, respectively. It was shown that such polystyrene aggregate concrete is more durable when it is subjected to sulfate attack or freeze-thaw cycles[8].

The water demand for all of the mixes was lower than anticipated (see Table 3). An excess of water resulted in the cement paste segregating from the EPS beads. EPS beads, however, is hydrophobic and it has been reported that water absorption is zero even when the beads are immersed in water continuously for one month[16].

Fig. 3 shows the variation in compressive strength with PC/EPS ratio. The 28-day compressive strength is increasing with increase of PC/EPS ratio. The same trend can be seen from Fig. 4 for relationship between densities and compressive strength. The 28-day compressive strength varied from 0.11 to 38.50 MPa and densities changed between 464 and 1940 kg/m$^3$, respectively. When cement ratio decreased from 1/1 to 3/4, 1/2 and 1/4 compressive strength decreased 77.84%, 86.00%, 92.80% and 99.70% respectively. The strength of concrete is mainly influenced by the strength of the aggregate[2] and it is known that the EPS beads have almost zero strength[1], therefore, this wide

Table 4—Strength and density of EPS concrete mixes

| Mix type | Fresh concrete density (kg/m$^3$) | Hardened concrete density (kg/m$^3$) | Decreasing ratio of density compare with control sample (%) | 28 days Compressive strength (MPa) | Decreasing ratio of compressive strength compare with control sample (%) |
|---|---|---|---|---|---|
| 1 | 471 | 464 | 76 | 0.11 | 99.70 |
| 2 | 1059 | 832 | 57 | 2.74 | 92.80 |
| 3 | 1183 | 1024 | 47 | 5.39 | 86.00 |
| 4 | 1371 | 1192 | 39 | 8.53 | 77.84 |
| 5* | 1952 | 1940 | - | 38.50 | - |

*Control sample

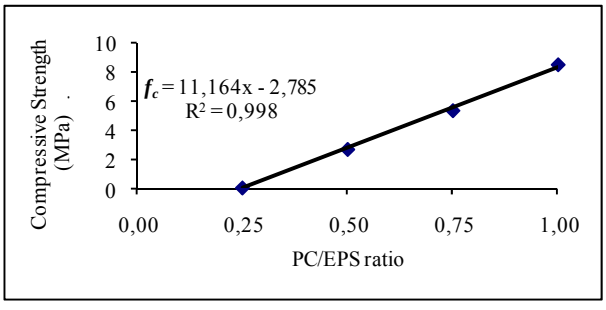



Fig. 3—Relationship between 28 days compressive strength and PC/EPS ratio by volume

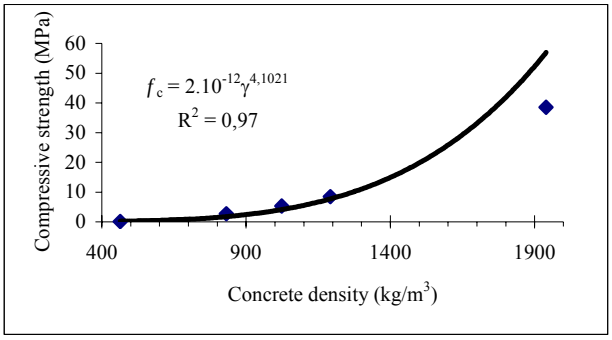



Fig. 4— Relations between hardened concrete density and 28 days compressive strength

variation of concrete strength with PC/EPS beads ratios may be mainly due to the negligible strength of EPS beads. Furthermore, for lightweight aggregate concrete, it is more relevant for mix design purpose to relate strength to cement content [3].

The relationship between PC/EPS ratio and compressive strength was linear and the determination coefficient was 0.998, when control sample value that was made up of 10% Portland cement was excluded (see Fig.3).

The density of the concrete can be controlled by varying the PC volume in the mix. The strength of EPS concretes appears to increase linearly with an increase in concrete density, or with an increase in the PC volume.

Density is one of the important parameters which can control many physical properties in lightweight concrete and it is mainly controlled by the amount and density of lightweight aggregate[6]. The previous studies indicate that the density of EPS concrete decreases with increase in volume of EPS aggregate and hence results in a decrease in compressive strength of the concrete[2,3,16,17]. The relationship between compressive strength and hardened concrete density of EPS aggregate concrete is shown in Fig. 4. The strength of EPS concretes was found to be directly proportional to the concrete density. The relationship between concrete density and compressive strength based on the results of EPS concretes with densities ranging from 464 to 1940 kg/m$^3$ can be proposed as:

***($f_c$).***

$$f_c = 2.10^{-12}.\gamma^{4.1021} \quad \ldots \quad (2)$$

Where $f$c is the compressive strength (MPa) and $\gamma$ is the density (kg/m$^3$) of the EPS concrete.

As a result of this investigation, by incorporating the EPS beads at different volume percentages in the concrete, mortar, or cement paste, a wide range of concrete densities can be achieved.

## Conclusions

Based on the experimental study carried out on EPS beads concrete, the following conclusions may be drawn:

(i) Density of EPS' concrete has significantly influenced by the PC/EPS ratio.

(ii) Densities are more sensitive to the change in the slump value than the w/c ratio.

(iii) The EPS beads have a closed cellular structure, increasing their volumetric proportion in the mixes decreases markedly the compressive strength.

(iv) It was observed that, increasing vibration duration causes accumulation of the beads over the mould.

(v) Super-plasticizer increased workability of the all concrete mix.

(vi) The 28-day compressive strength and the dry concrete density varied from 0.11 to 38.50 MPa and from 464 to 1940 kg/m$^3$, respectively

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