Lightweight Concrete Incorporating Waste Expanded Polystyrene

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Abstract: This paper covers the results of an experimental investigation on mechanical and durability properties of concrete containing waste polystyrene based lightweight aggregate called Stabilised Polystyrene (SPS) as a partial replacement of natural aggregates. The properties investigated in this paper were water absorption by capillary action and total absorption, compressive strength and ultrasonic pulse velocity (UPV). The composite aggregate was formed with 80% waste polystyrene which was shredded to different sizes, 10% of a natural additive to improve the resistance to segregation and 10% Portland cement. The natural fine aggregate were replaced with 0%, 30%, 60% and 100% (by volume) of SPS. There was an increasing in water absorption and a decreasing in compressive strength and UPV with the increase in SPS aggregate content in concrete.

Background Literature

Reuse and recycling of wastes materials is considered the best environmental alternative for solving the problem of disposal. One of such waste materials is Expanded Polystyrene (EPS). Polystyrene is a thermoplastic substance and has the potential use in concrete to produce lightweight concrete by replacing normal aggregate in concrete.

The Idawati ismail [1] project reports the results of an experimental investigation into the properties of hardened concrete bricks containing expanded polystyrene beads. The beads are used as part of sand replacement in the mixes. It was found that polystyrene concrete is very prone to segregation and has low compressive strength. The properties of the bricks are mainly influenced by the content of polystyrene beads in the mix. The results indicate that polystyrene concrete mix with certain portion of the beads may provide as a suitable alternative material in the construction industry.

The Le Roy et al. [2] paper deals with the mix design and mechanical properties of very lightweight concrete (LWC) made of expanded polystyrene spheres (EPS) and very high performance matrix. In their paper, like others, they added a super-plasticiser and adjusted the dosage. In their paper it is also shown that the lower the inclusion size, the higher the compressive strength of the hardened concrete.

The Babu et al. [3] study investigated the effect of polystyrene aggregate size on strength and moisture migration characteristics of lightweight concrete containing fly ash as a supplementary cementitious material. The results indicate that for comparable aggregate size and concrete density, concrete with unexpanded polystyrene (UEPS) aggregate exhibited 70% higher compressive strength than EPS aggregate. Moreover, the moisture migration and absorption results indicate that the EPS concrete containing bigger size and higher volumes of EPS aggregate show higher moisture migration and absorption.

The total water absorption values in the Miled et al. [4] investigation show a decreasing trend with increasing density of the concretes. It was also observed that the lower the EPS bead size, the greater the concrete compressive strength, for the same concrete porosity. Moreover, it was observed that this particle size effect is very pronounced for low porosity concretes which failure mode is quasi-brittle, whereas it becomes negligible for very high porosity concretes which failure mode is more ductile.

The main theme of the previous work done on EPS aggregate in concrete as mentioned above has been that with an increase of EPS in the concrete itself will result in a low-density and a weaker concrete, this is due to the EPS particles being quite weak. Most studies have used super plasticisers and fly ash to increase the workability of the concrete. Additives like these may not be environmentally friendly and readily available in developing countries. The main aim of present study is to find an extra source for lightweight aggregate using new technique and minimise the environmental impacts by reusing/recycling waste EPS.

Experimental Details

Four different mixtures were used for this experimental investigation. In mixtures 1, 2, 3 and 4 the natural fine aggregate was replaced with 0, 30, 60 and 100% (by volume) of Stabilised Polystyrene (SPS), respectively. The control mixture (M1) had a proportion of 1 (cement): 6 (natural fine aggregate). The water to cement ratio (W/C) of 0.6 was used for all mixtures. Further details about the mixtures are presented in Table 1. In order to achieve a uniform dispersion of the waste polystyrene particles in concrete, a natural fine material is used to avoid segregation as part of the manufacturing process of the lightweight aggregate (Fig. 1). The material being tested is the lightweight aggregate called stabilised polystyrene (SPS) which consists of cement (10%), a natural material (10%) and 80% waste polystyrene. The particle size distribution according to BS EN 933-1 [5] and properties of natural sand and SPS aggregate are given in Tables 2 and 3, respectively. The cement used was Portland cement (PC). The chemical characteristics of cement are given in Table 4. The natural fine aggregate used complied with the British standard requirements.

Table 1: Details of mixtures

Series NO.	W/C	Mix NO.	Mix Code	SPS* (%)	Mixture Constituents (kg/m³)		
					Cement	Water	(NA** + SPS)
1	0.6	1	M1	0	320	192	(1920 + 0%SPS)
		2	M2	30	320	192	(1344 + 30%SPS)
		3	M3	60	320	192	(768 + 60%SPS)
		4	M4	100	320	192	(0 + 100%SPS)

* Stabilised Polystyrene (SPS), (% by volume) **NA: natural aggregate

Table 2: Particle size distribution (sieving) of aggregates

Sieve (mm)	Cumulative Passing (%)	
	SPS aggregate	Natural aggregate
12.5	100	100
10	95.1	100
8	86.5	100
4	59.7	96.6
2	40.7	77.6
1	25.4	64.9
0.5	16.5	51.7
0.250	10.8	16.1
0.125	6.2	3.6
0.063	1.6	0.7
Filler	0.0	0.0

Table 3: Properties of aggregates

Properties	SPS	Natural fine aggregate
Bulk density (Kg/m^3)	457	1673
Fineness modulus	5.58	3.89
Specific gravity (SSD)	0.80	2.67
Water absorption (%)	13	1.1

Table 4: Chemical compositions of the cement

Constituent	Values
Loss on ignition	1.5 (%)
Insoluble residue	0.5 (%)
Brightness	43 (%)
SiO_2	22.8 (%)
Al_2O_3	3.8 (%)
Fe_2O_3	1.4 (%)
CaO	66.5 (%)
MgO	0.8 (%)
SO_3	3.3 (%)
K_2O	0.7 (%)
Na_2O	0.1 (%)
Cl	<0.1 (%)
Flexural tensile strengths (28Days)	9.9 (Mpa)
Compressive strengths (28 Days)	75.5 (Mpa)

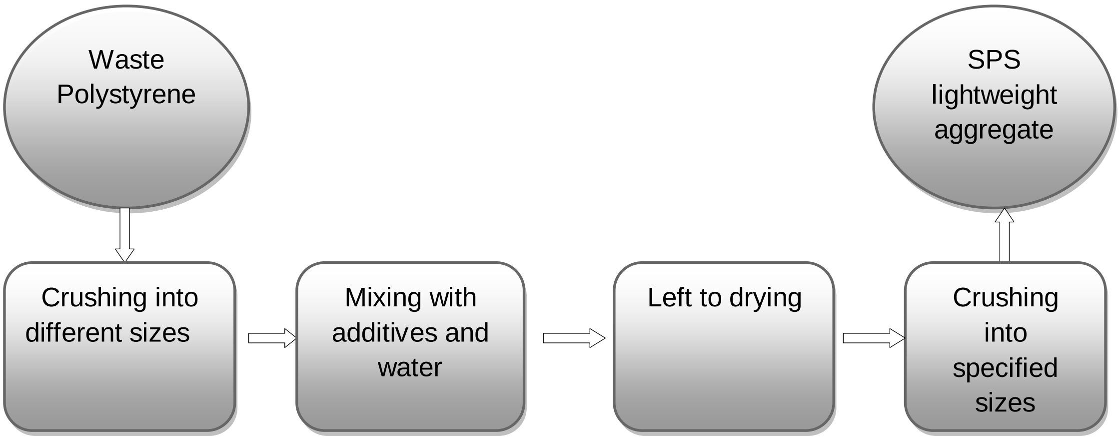

Fig. 1: Manufacturing process of SPS aggregate

Concrete was mixed in a planetary mixer of 100 litres capacity. SPS aggregate were wetted with 1/3 of the mixing water first before adding the remaining materials. Although in manufacturing process of SPS aggregate a natural material (10%) and cement (10%) have been used to improve the resistance to segregation but care has been exercised during mixing, pouring and compacting the fresh concrete.

The workability of the fresh concretes was measured by slump-test according to BS EN 12350-2:2009 [6]. Cubes of 100mm size were used for the determination of compressive strength and ultrasonic pulse velocity. Compressive strength test was carried out using testing machine of 3000KN capacity at the loading rate of 0.6 MPa/s complied with BS EN 12390-3:2009 [7].

Ultrasonic pulse velocity (UPV) test was carried out complied with BS EN 12504-4:2004 [8]. Specimens of 100 x 100 x 50mm size were cast for the determination of water absorption by total and capillary action. After casting, specimens were covered with plastic sheets to minimise the moisture loss and left in the laboratory at 20°C for 24 hours. After that, de-moulding took place and specimens were placed in water for different curing times. The data at 7-day of curing were reported in this investigation. For capillary water absorption and total water absorption tests, samples were dried in an oven at 80ºC to get constant dry mass. The specimens were then cooled in an airtight container at room temperature before testing.

For capillary water absorption test, the absorption of water by concrete specimens were determined by measuring the increase in the mass resulting from absorption of water as a function of time when only one surface of the specimen (2-3mm) is exposed to water on a support device (Fig. 2). During the test period, weight gain was monitored at intervals of 1, 3, 5, 7, 10, 20, 30, 45, 60, 120, 180, 1440 and 2880 minutes. The water level was kept constant throughout the test. The water absorption values are the average of three test samples. The weight (g) of water absorbed per unit area (mm^2) was plotted against the square root of time (minute). The units are in $g/mm^2 \ min^{1/2}$.

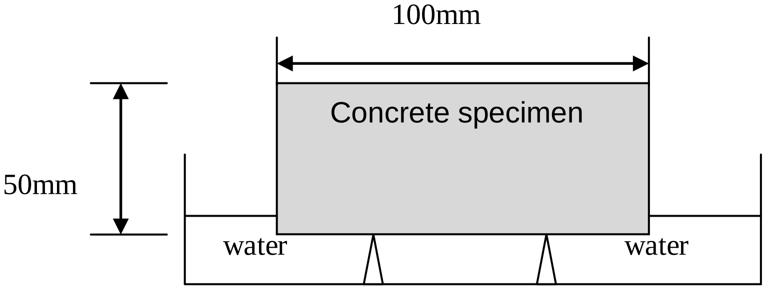

Fig. 2: Diagrammatic of CWA test set up

Results and Discussions

Workability and Density

None of the mixtures recorded any slump. This was mainly due to the lack of any super-plasticiser which would have improved the workability.

As we know the density of concrete significantly affects the strength and ultrasonic pulse velocity (UPV) [9, 10]. The measurement of UPV can be used for the determination of the uniformity of concrete, the presence of cracks or voids, changes in properties with time and in the determination of dynamic physical properties. The strength and UPV of SPS concretes increased with increasing the concrete density. The density of SPS aggregate was much less than that of natural aggregate. The densities for SPS lightweight concretes were about 1200–2100 kg/m^3 (Fig. 3).

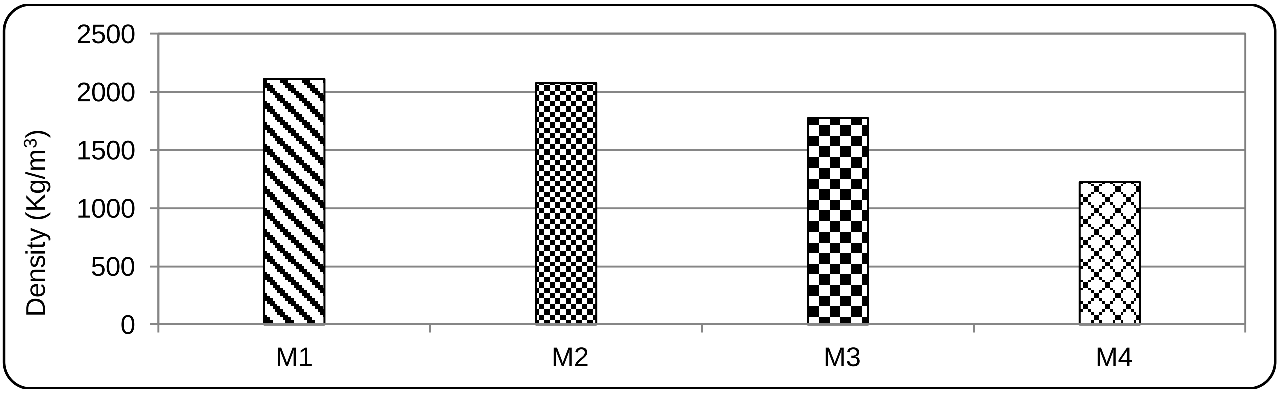

Fig. 3: Densities of mixtures

Water Absorption by Total and Capillary Action

The amount of water absorbed per unit area for concrete containing SPS aggregate at the age of 7-day of curing is shown in Fig. 4. Also the water absorption of concretes at 30-min and final absorption is shown in Fig. 5. Total water absorption is generally measured by its increase in mass as a percentage of the dry mass when totally submerged in water.

There is higher amount of water uptake with the increase in SPS content at the first 30 minutes of the test period. There is also higher water absorption by total and by capillary action when SPS aggregate is incorporated in the mixes. Mixes containing 60 and 100% SPS as replacement of natural fine aggregate show substantially higher water uptake. There is a very small difference in water uptake between the mixes 1 and 2 at 7-day age and this difference becomes noticeable for mixes 3 and 4. That means mixtures containing 60 and 100% SPS as replacement of natural sand show substantially higher water uptake compared with mixtures containing 0 and 30% SPS aggregate. For example at 7-day of curing, the water uptake at the end of the test period by the mixture containing 100% SPS is nearly 2 times more than that of the control mixture (0% SPS). Further details about the determination of water absorption by capillary action and total absorption are reported elsewhere [11, 12].

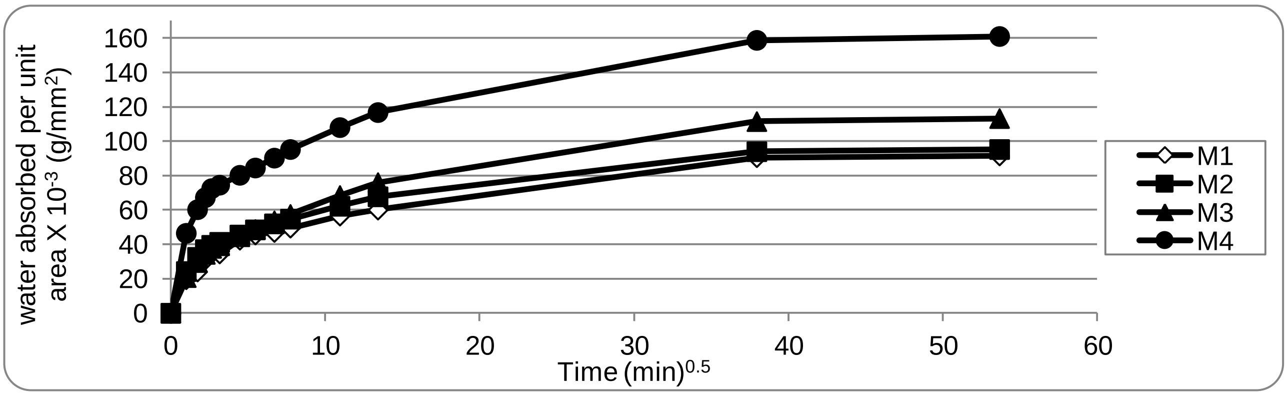

Fig. 4: CWA of concretes containing varying amounts of SPS at 7-day age

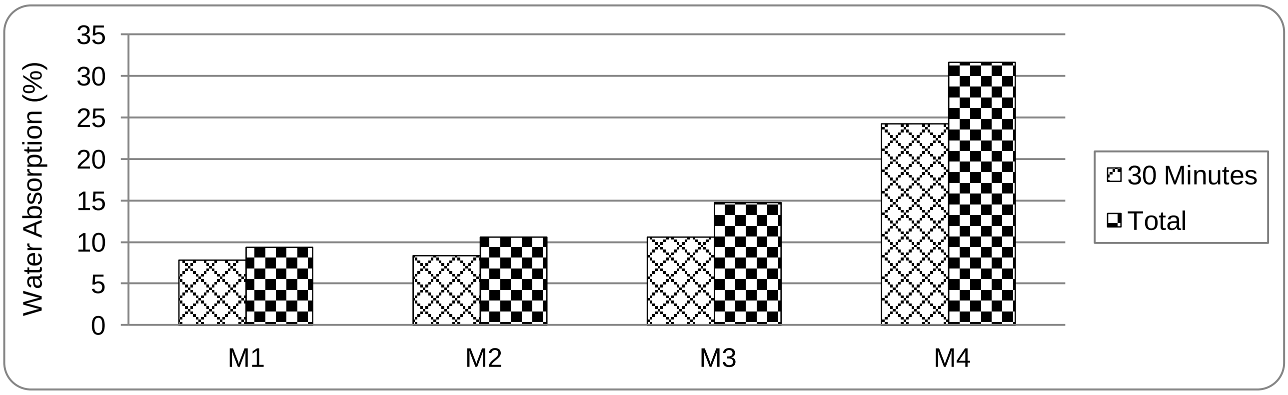

Fig. 5: Water absorption of concretes at 30 minutes and total absorption

Compressive Strength and UPV

The compressive strength at the age of 7 days of curing for concretes containing varying amounts of SPS aggregate is shown in Fig. 6. There is a systematic decrease in compressive strength as the amount of SPS in concrete is increased. For example, the strength for the control mixture (0%SPS) is 11.41 MPa and this drops down to 3.79 MPa for the mix containing 100% SPS as a replacement of natural sand. For mixtures containing 30%, 60% and 100% SPS, the corresponding decrease in strength is 1%, 41% and 67%, respectively. According to the results reported in Figure 6, there is a very small difference in strength between the mixtures 1 and 2. The decrease in compressive strength of the concrete may be due to the replacement of natural sand with SPS and the resulting increase in the surface area of fine particles, which can lead to weakening of interfacial zone between the SPS and the cement paste. The SPS specimen's failure observed was to be more gradual and compressible without full disintegration [13].

Fig. 7 plots the ultrasonic pulse velocity (UPV) versus SPS replacement levels for the various concrete mixtures. The trend is similar to that of strength, in that an increase in SPS leads to a decrease in UPV. According to the results reported in Fig. 7, again there is a very small difference in UPV between the mixtures 1 and 2 as the corresponding reduction for M2 is only 4%.

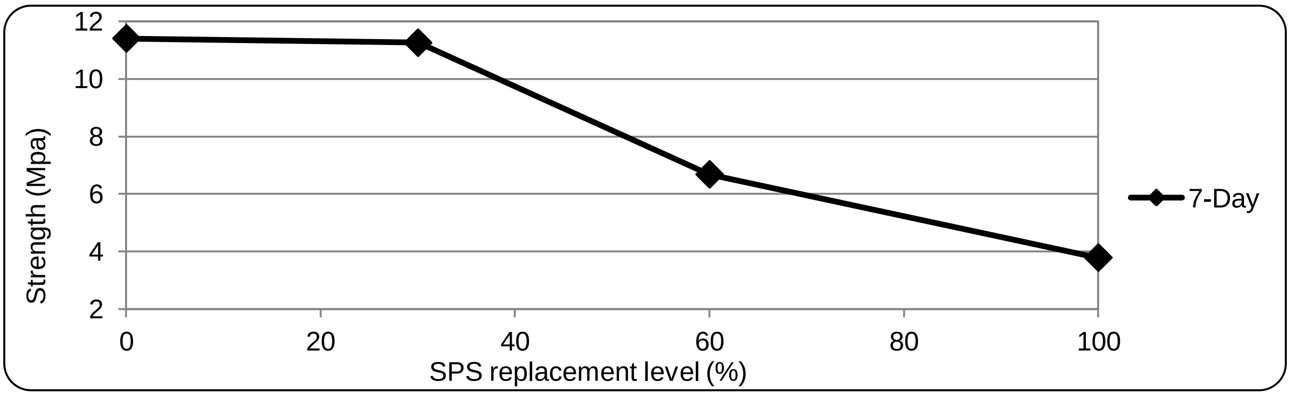

Fig. 6: Compressive strength of concretes containing varying amounts of SPS at 7-day age

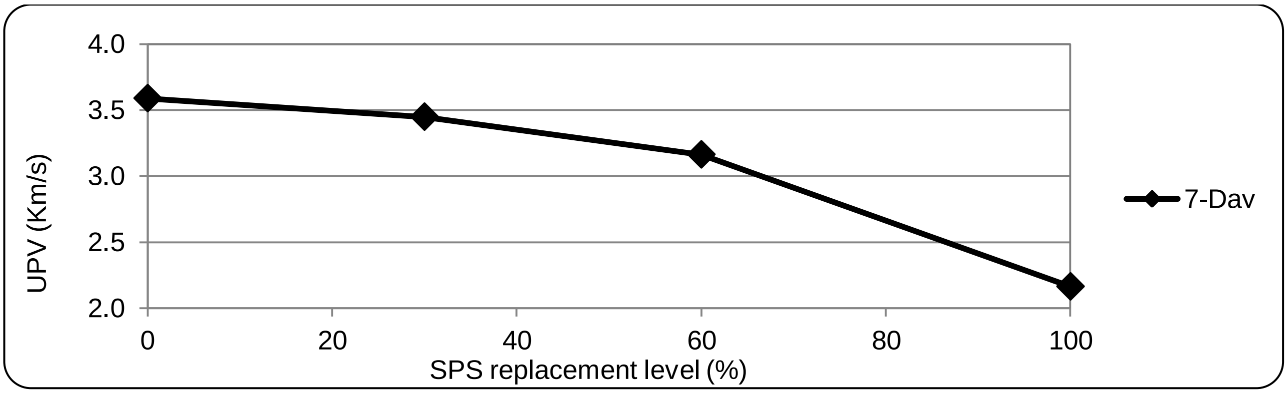

Fig. 7: Ultrasonic Pulse Velocity of concretes containing varying amounts of SPS at 7-day age

Conclusions

Although here is a tendency for the water absorption (capillary and total) to increase when natural sand is replaced with increasing amounts of SPS aggregate, replacing up to 30% of natural sand with SPS aggregate does not cause a noticeable increase in water absorption. Also replacing up to 30% of natural aggregate with SPS does not cause a noticeable decrease in strength and UPV as the corresponding reduction in strength and UPV was 1% and 4%, respectively. Mixtures containing 0 and 30% SPS aggregate as replacement of natural sand show substantially lower water uptake compared with mixtures containing 60 and 100% SPS aggregate. If SPS aggregate is manufactured correctly it can be a competent lightweight aggregate.

Currently, several engineering studies including weathering resistance, firing resistance, drying shrinkage, expansion and structural properties of concrete made with SPS aggregate at different curing times are under investigation before this sustainable novel lightweight material could be proven OK for use in civil engineering applications.

The main recommendation for further possible future work is to investigate the resistance of SPS aggregate to chemicals and how the clay content in the SPS aggregate affects the final concrete strength using different methods of curing.

Acknowledgments

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