World Applied Sciences Journal 21 (9): 1356-1360, 2013
ISSN 1818-4952
© IDOSI Publications, 2013
DOI: 10.5829/idosi.wasj.2013.21.9.20213

Lightweight Concrete Made from Waste Polystyrene and Fly Ash

[1]B.A. Herki, [1]J.M. Khatib and [1,2]E.M. Negim

[1]School of Technology, University of Wolverhampton, Wolverhampton, WV1 1LY, UK
[2]Department of Polymers and Pigments, National Research Center, Dokki, Cairo, Egypt

Abstract: Concretes containing Portland cement, fly ash as the supplementary cementitious material, natural fine aggregate and a novel lightweight material called Stabilised Polystyrene (SPS)aggregatewere investigated. This paper presents the results of an experimental work on the effects of waste Expanded Polystyrene (EPS) based lightweightaggregate called Stabilised Polystyrene (SPS) and fly ash in concrete. The composite aggregate was formed with 70% waste polystyrene which was shredded to coarse and sand sizes, 10% of anatural material to improve the resistance to segregation of EPS and 20% Portland cement. Nine different mixtureswith water to binder ratio (W/B) of 0.8 with varying SPS content ratios of 0, 60 and 100% as partial replacement of natural fine aggregate by equivalent volume at the fly ash replacement levels of 0, 20 and 40% with Portland cement were prepared and tested. The properties of concrete investigated in this paper were compressive strength and ultrasonic pulse velocity (UPV) at the age of 28-day. The results indicate that there is a decrease in compressive strength and UPV with increasing amounts of SPS and fly ash in concrete.

Key words: Compressive Strength · Fly Ash · Stabilised Polystyrene · UPV · Waste Polystyrene

INTRODUCTION

Currently millions of tons of waste polystyrene are produced in the world. This will ultimately cause pollution and is harmful to the ecosystem. National and international environmental regulations have also become more inflexible, causing this waste to become increasingly expensive to dispose. Therefore, utilising waste polystyrene in concrete production not only solves the problem of disposing this ultra-light (up to 95% air) solid waste but also helps preserve natural resources.

Sabaa and Ravindrarajah [1] studied engineering properties of polystyrene (PS) aggregate concrete by partially replacing natural coarse aggregate with equal volume of the chemically coated polystyrene at the levels of 30, 50 and 70%. They found that compressive strength, unit weight and modulus of elasticity decreased and drying shrinkage and creep increased with increasing PS aggregate replacement in concrete.

Babu [2] investigated the behaviour of lightweight expanded polystyrene concrete containing silica fume and found that the rate of strength development increased and the total absorption values decreased with increasing in replacement levels of silica fume in concrete. It was also found that the strength of EPS concrete marginally increased as EPS bead size decreased and increased as the natural coarse aggregate size in concrete increased.

The Saradhi Babu *et al.* [3] study covers the use of expanded polystyrene (EPS) beads as lightweight aggregate, both in concrete and mortar. The mechanical properties of EPS concretes containing fly ash were compared to the results of concretes containing Portland cement alone as the binder. The compressive strength of the EPS concretes containing fly ash show a continuous gain even up to 90 days, unlike that reported for Portland cement in literature. It was also found that the failure of these concretes both in compression and split tension was gradual as was observed for the concretes containing plastic shredded aggregates. This study tested mixtures with densities as low as 600kg/m^3.

The results of compressive tests in the Miled *et al.* [4] investigation confirmed the presence of a particle size effect on the EPS concrete compressive strength since it was observed that the smaller the EPS bead size, the greater the concrete compressive strength, for the same concrete porosity.

Corresponding Author: B.A. Herki, School of Technology, University of Wolverhampton, Wolverhampton, WV1 1LY, UK.

Most research on EPS concretes as mentioned above has shown a decrease in the durability performance and the engineering properties of concrete with increasing the amount of polystyrene aggregate in mixtures and an increase in strength with smaller EPS bead size in concrete. The studies on EPS concretes reviewed above have also shown that mixtures produced using the ordinary vibration method will lead to a large number of particles floating upward and serious concrete segregation, resulting in EPS lightweight aggregate concrete with reducing its various performances. This is due to the ultra-light EPS particles and being quite weak. A great deal of research has used super plasticisers and fly ash to increase the workability of the concrete. Additives like these may not be readily available in developing countries. An abundant natural resource in most countries should be tested as an alternative material to improve the resistance to segregation of EPS in concrete. The purpose of this study is to investigate the engineering properties of concrete containing lightweight aggregate using a new technique of processing for waste expanded polystyrene as partial substitution of natural aggregate.

MATERIALS AND METHODS

Total of 9 different mixtures were made for this investigation. The control mixture (0%SPS+0%FA) had a proportion of 1 (cement): 6 (Natural fine aggregate). The natural fine aggregate was replaced with 0, 60 and 100% (by volume) of Stabilised Polystyrene (SPS) aggregate. The Portland cement was replaced with 0, 20 and 40% (by mass) of fly ash. The water to binder ratio (W/B) of 0.8 was used for all mixtures and no adjustment to the water content was made for mixtures incorporating fly ash (FA). Further details about the mixtures are presented in Table 1.

The binders used were Portland cement (PC) and high carbon PFI fly ash (FA) which was obtained from a local power station in the UK. The chemical characteristics of cement and FA are given in Table 2. The natural fine aggregate used complied with the British standard requirements.

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 SPS lightweight aggregate. Further details

Table 1: Details of mixtures

	Binder content (%)			Mixture Constituents (kg/m^3)		
Mix NO.	PC	FA**	SPS* (%)	PC + FA	Water	(NA + SPS)
M1	100	0	0	320 + 0	256	(1920 + 0%SPS)
M2	100	0	60	320 + 0	256	(768 + 60%SPS)
M3	100	0	100	320 + 0	256	(0 + 100%SPS)
M4	80	20	0	256 + 64	256	(1920 + 0%SPS)
M5	80	20	60	256 + 64	256	(768 + 60%SPS)
M6	80	20	100	256 + 64	256	(0 + 100%SPS)
M7	60	40	0	192 + 128	256	(1920 + 0%SPS)
M8	60	40	60	192 + 128	256	(768 + 60%SPS)
M9	60	40	100	192 + 128	256	(0 + 100%SPS)

* Stabilised Polystyrene (SPS), (% by volume) ** Fly ash (% by mass)

Table 2: Chemical compositions of the cement and FA

	Values (%)	
Constituent	FA	Cement
SiO_2	13.2	22.8
Al_2O_3	6.7	3.8
Fe_2O_3	6.2	1.4
CaO	1.4	66.5
MgO	1.1	0.8
SO_3	1.1	3.3
K_2O	1.8	0.7
Na_2O	6.3	0.1
Cl	0.1	<0.1

Table 3: Properties of aggregates

Properties	SPS aggregate	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

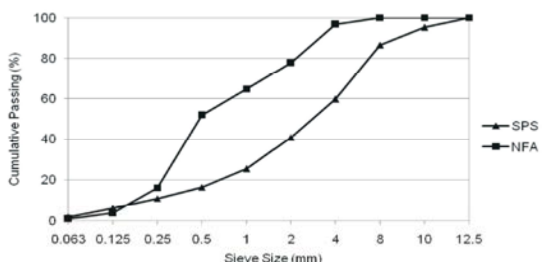

Fig. 1: Particle size distribution (sieving) of aggregates

about the production process of the SPS aggregate has been reported elsewhere [5]. The material being tested is the lightweight aggregate called stabilised polystyrene (SPS) comprising cement (20%), a natural material (10%) and waste polystyrene (sand + coarse sizes, 70%). The particle size distribution according to BS EN 933-1 [6] and properties of natural fine and SPS aggregates are given in Figure 1 and Table 3, respectively.

Concrete was mixed in a planetary mixer of 100-litres capacity. SPS aggregate was 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%) has been used to improve the resistance to segregation of EPSenough 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 [7]. Specimens were cast in steel moulds. 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 according to BS EN 12390-3:2009 [8]. Ultrasonic pulse velocity (UPV) test was carried out according to BS EN 12504-4:2004 [9]. 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. After casting, specimens were covered and left in the laboratory for 24 hours. Then, demoulding took place and specimens were placed in water for different curing times. The data at 28-day of curing were reported in this investigation.

RESULTS AND DISCUSSIONS

Workability and Density: The density values for concretes were reported in Figure2. The workability for the mixtures M1 (0%SPS+0%FA), M4 (%SPS+20%FA) and M7 (0%SPS+40%FA) was just enough to be compacted and could also be finished, but all other mixtures were flexible and very easy to work with and compaction and finishability were very easy. The workability of the concretesincreased with increasing the replacement level of SPSaggregate in concrete up to 60% then decreased for 100%SPS replacement. As mentioned earlier, the majority of studies have used super plasticisers and fly ash to increase the workability of the concrete but according to the current investigation results, the workability of concretes decreased with increasing the replacement level of FA. This was mainly due to the high carbon content in the FA which would have demanded more mixing water.

According to the results reported in Figure 2, the density of concretes decreased with increasing the replacement level of SPS aggregate but increasing the replacement level of FA had little effect on the density of concretes. The density of SPS aggregate was much less than that of natural aggregate.

Compressive Strength and UPV: The compressive strength at the age of 28-day of curing for concretes containing varying amounts of Stabilised Polystyrene (SPS) is shown in Figure 3. There is a systematic decrease in compressive strength as the amount of SPS aggregate and FA in concrete is increased. For example, at the age of 28-day of curing the strength for the control mix (0%SPS+0%FA) is 16 MPa and this drops down to 8MPa for the mix containing 60%SPS+20%FA as a replacement of natural sandand Portland cement, whichthe decrease percentage in strength is about 50%. The decrease in compressive strength of the concretes may be due to the low content of cement and lack of natural coarse aggregate. It is clear that the mixes containing coarse aggregate show increase in strength and slight increase in density. The decrease in compressive strength of the concrete may also be due to the replacement of natural sand with SPS and the resulting increase in the surface area of very fine particles, which can lead to weakening of interfacial zone between the aggregates and the cement paste. Similar result has been reported by Tang *et al.* [10] and Kan and Demirboga[11].

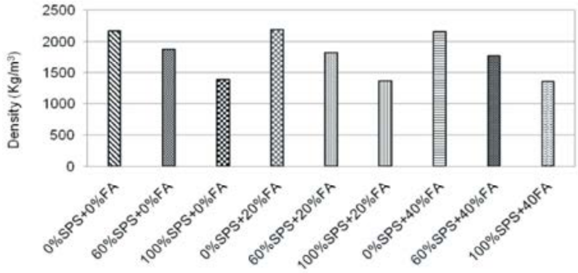

Fig. 2: Effect of SPS aggregate and FA on density of mixtures

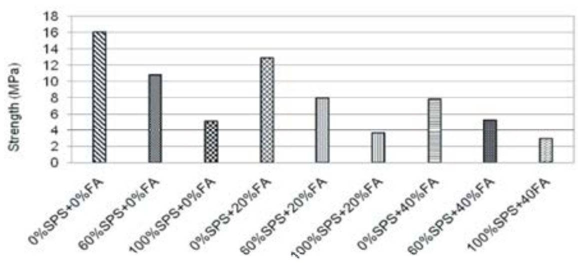

Fig. 3: Compressive strength of concretes containing varying amounts of SPS and FA at 28-day age

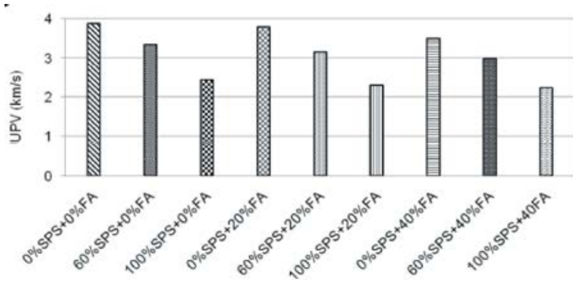

Fig. 4: UPV of concretes containing varying amounts of SPS and FA at 28-day age

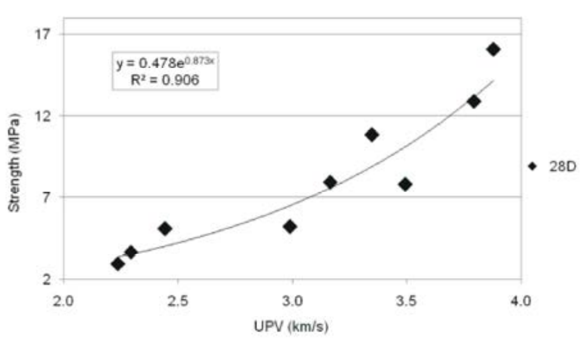

Fig. 5: Relation between compressive strength and UPV

As we know the density of concrete significantly affects the strength and ultrasonic pulse velocity (UPV). The strength and UPV of SPS concretes increased with increasing the concrete density also decreased with increase in SPS aggregate content.

The failure mode of the specimens containing SPS aggregates under compressive load did not exhibit the typical brittle failure normally associated with the normal aggregate concrete. The specimen's failure observed was to be more gradual and compressible without full disintegration. This result concurs with the results obtained by Babu [2].

As shown in Figure 4, the trend is similar for the ultrasonic pulse velocity (UPV) in which an increase in SPS and FA leads to a decrease in UPV. At 28-day age, control mixture (0%SPS+0%FA) achieved a pulse velocity of 3.88 km/s, whereas Mix5 (60% SPS+20%FA) achieved a pulse velocity of 3.16 km/s, a decrease of 19% in comparison with the pulse velocity of control mixture. The pulse velocity was calculated from the formula:

$$V = L/T$$

Where:

- Vis the pulse velocity, in km/s
- Lis the path length, in mm
- Tis the time taken by the pulse to transverse the length, in ìs.

Figure 5 shows the correlation between compressive strength and UPV. An increase in UPV leads to an increase in compressive strength. This is in agreement with the results obtained by Babu *et al.* [2] and Kan and Demirboga [11] as discussed earlier. An exponential function seems to better describe the correlation between strength and UPV for all mixtures: $Y=0.4782e^{0.8733x}$, with R^2 = 0.9069 indicating strong correlation, where X is the UPV and Y is the compressive strength.

Currently, some other tests including weathering resistance, firing resistance, drying shrinkage, expansion, total water absorption, capillary water absorption and structural properties of concrete made with SPS aggregate using different binders including FA at different curing times are under investigation before this sustainablelightweight material could be proven OK for use in civil engineering applications.

CONCLUSIONS

There is a tendency for the compressive strength and UPV to decrease when natural sand and Portland cement are replaced with the increasing amounts of Stabilised Polystyrene (SPS) aggregate and fly ash, respectively.

The level of decrease depends upon the replacement level of SPS aggregate and FA. However, adequate strength can be achieved using an appropriate replacement level of SPS aggregate and FA. For example at 28-day age the decrease percentage in strength and UPV for M5 (60%SPS+20%FA) is 50% and 19% respectively, in comparison with M1 (control mixture). If SPS aggregate is manufactured correctly, with appropriate concrete mix design, the utilisation of this novel lightweight aggregate made from waste Polystyrene (PS) in lightweight concrete production is possible. However more engineering testing needed to be done before the material could be proven OK for use in construction applications.

ACKNOWLEDGMENTS

The assistance from Soran University (Kurdistan-Iraq), Parry and Associates Ltd. and University of Wolverhampton civil engineering's laboratory is gratefully acknowledged.

REFERENCE

1. Sabaa, B. and R. S. Ravindrarajah, 1997. Engineering properties of lightweight concrete containing crushed expanded polystyrene waste. In: *Materials research society*, fall meeting, symposium MM, advances in materials for cementitious compos, Boston, USA,
2. Babu, K.G. and D.S. Babu, 2003. Behaviour of lightweight expanded polystyrene concrete containing silica fume. Cement and Concrete Research, 33: 755-762.
3. Babu, K.G., D.S. Babu and T.H. Wee, 2005. Properties of lightweight expanded polystyrene aggregate concretes containing fly ash. Cement and Concrete Research, 35: 1218-1223.
4. Miled, K., K. Sab and R. Le roy, 2007. Particle size effect on EPS lightweight concrete compressive strength: Experimental investigation and modelling. Mechanics of Materials, 39: 222-240.
5. Herki, B.A., M.J. Khatib, D. Searle and P. Georgakis, 2012. Mechanical properties of concrete incorporating waste lightweight aggregate. 6th. International conference and workshop on the built environment in developing countries. Adelaide, Australia,
6. BS EN 933-1. 1997. Tests for geometrical properties of aggregates. Part 1: Determination of particle size distribution - Sieving method.
7. BS EN 12350-2. 2009. Testing fresh concrete. Part 2: Slump-test.
8. BS EN 12390-3. 2009. Testing hardened concrete. Part 3: Compressive strength of test specimens.
9. BS EN 12504-4. 2004. Testing concrete. Part 4: Determination of ultrasonic pulse velocity.
10. Tang, W.C., Y. Lo and A. Nadeem, 2008. Mechanical and drying shrinkage properties of structural-graded polystyrene aggregate concrete. Cement andConcrete Composites, 30: 403-409.
11. Kan, A. and R. Demirboğa, 2009. A novel material for lightweight concrete production. Cement and Concrete Composites, 31(7): 489-495.