Effects of some factors on compressive strength of structural polystyrene concrete

Hoang Minh Duc and Le Phuong Ly
Vietnam Institute for Building Science and Technology
E-mail: lephuongly.ibst@gmail.com

Abstract: Structural polystyrene concrete is a lightweight composite consisting of lightweight expanded polystyrene aggregates immersed in a cement matrix. Compressive strength of structural polystyrene concrete can be increased by increasing compressive strength of cement matrix. Increasing strength of lightweight expanded polystyrene aggregate or improving interfacial transition zone between them is inefficient because the strength of polystyrene beans and their bond with cement matrix are negligible. In this case, the characteristic of normal aggregate in cement matrix plays an important role. The research results in this paper show that increasing of maximum particle size of normal aggregate in cement matrix significantly decreases the compressive strength of polystyrene concrete with given density. Therefore, the coarse aggregate smaller than 10 mm is recommended for structural polystyrene concrete with density less than 1,600 kg/m³.

1. Introduction

The role of the mortar strength and the strength of link between phases depends on the intensity and properties of each component. According to [1], research on some types of concrete using various strengths aggregates on matrix has compressive strengths from 20 MPa to 40 MPa shown that concrete strength is directly proportional to aggregate strength. Structural polystyrene concrete which uses lightweight aggregates has devoid of strength, it may not appear that the area with a strength greater than the strength of matrix, it does not exist optimal region compressive strength.

Structural polystyrene concrete (SPC) concrete uses expanded polystyrene (EPS) aggregates which is impervious, does not interact with adhesives and has negligible strength. EPS aggregates are added to the matrix to reduce the density of concrete. It can be considered that SPC is a system of EPS aggregates evenly distributed in the matrix. Therefore, the properties of the matrix greatly affect the compressive strength of SPC.

Figure 1 shows that expanded clay aggregate concrete with compressive strength of 20 MPa have to use minimum of matrix compressive strength about 20 MPa. However, the study [4, 5] used a matrix as fine concrete with high strength up to 120 MPa to make structural polystyrene concrete with compressive strength is 20 MPa at about density from D1400 to D1600. This shows that when reducing the ratio density of matrix, the strength of structural polystyrene concrete significantly decreases. In Vietnam, using
high strength fine concrete is not widely. Therefore, it is necessary to study structural polystyrene concrete with density not more than 2.000 kg/m³ and strength at B15, based on using normal concrete. It is possible to determine the type of matrix suitable for making SPC if the relationship between the matrix characteristics and the concrete strength of SPC is clarified.

Figure 1. Dependence of concrete strength on matrix strength when using aggregate.

On the other hand, EPS aggregates have negligible strength. So, hardened matrix is considered as bearing frame in structure of SPC. The compressive strength of SPC depends on the compressive strength of matrix. Therefore, the effect of the distance between the EPS aggregates on the bearing capacity of the matrix wall is very obvious because of the heterogeneity of the matrix wall. The structure of the wall matrix is composed of cement mortar and normal aggregate. Correlation between wall thickness of matrix and diameter size of matrix’s maximum coarse aggregates is very important to the bearing capacity of matrix wall.

Researching [2] on polystyrene concrete with unit weight from 400 kg/m³ to 700 kg/m³, using fly ash and silicafume to enhance the compressive strength of the matrix. However, there were no coarse aggregates in that matrix, just only cement and mineral. Therefore, these studies have not clarified the role of the matrix’s aggregate to the properties of polystyrene concrete.

BKP, which has density about 1,400-2,000 kg/m³, spacing between EPS aggregates is large enough to use coarse aggregate in the matrix. Therefore, the correlation of particle size in SPC can be divided into 3 cases which are particle size of EPS aggregates greater, equal or smaller than the particle size of coarse aggregate (Dmax aggregate).

When the particle size of EPS aggregate is larger than matrix’s maximum aggregates, the cement paste surrounds the EPS, the EPS aggregate is seem to be as coarse aggregate. After hardening, the cement paste surrounds the EPS forms a bearing frame for SPC. The wall thickness made by this cement mortar is equal to the distance between the EPS. It is assumed that EPS aggregates are evenly distributed in concrete components according to the most closely arranged model. Then, distance between EPS aggregates is the same.

In case the particle size of EPS aggregate is less than or equal to the maximum particle size of the matrix’s aggregate. When matrix volume ratio is high and density of concrete mixture is high, the wall thickness created by matrix is equal to the distance between EPS. However, when the ratio volume of matrix decreases, the appearance of coarse aggregates may affect the EPS distribution in concrete. At that
time, it can be considered as EPS evenly distributed in the cement mortar mixture of matrix. Thus, the effect of the size of normal aggregate in the matrix on the strength of SPC increased.

This paper presents the research carried out at the Institute of concrete technology - Vietnam Institute for Building Science and Technology about the impact of compressive strength and the maximum particle size of the matrix on compressive strength of SPC which has density from 1,400 kg/m³ to 2,000 kg/m³.

2. Materials and testing methods
Commercially available EPS aggregates was used in this study. Diameter size of EPS aggregate was from 1.5 mm to 3.0 mm, with the density of 19.7 kg/m³, bulk density of 11.1 kg/m³. The study used PC40 But Son cement (symbol X) with compressive strength at 28 days of 44.3 MPa, specific gravity of 3.05 g/cm³, fineness of 3,410 cm²/g.

Silicafume D920 (SF symbol) has a specific gravity of 2.2 g/cm³, average particle size is 1 micrometer, and the activity index strength is 89%. The lime stone powder is ground from carbonate stone with the fineness the same cement, equivalent to 3,470 cm²/g of specific surface.

The study also used superplasticizer (symbol SP) polycarboxylate PCA1, capable of reducing water by 25-30%, with a density of 1.05 ± 0.02 (g/ml).

To adjust the viscosity of concrete mixture using an additive with the nature of Hydroxypropyl methyl cellulose (symbol MC), with a pH of 4-8, viscosity of 35,000 - 47,000 mPa.s (2% solution at 20 °C), white powder.

Coarse aggregate material is carbonate stone, including D1 and D2 types, with the maximum particle sizes of 10 mm and 20 mm. Fine aggregate consists of 3 types which symbols are C1, C2, C3 with the maximum particle size respectively 0.63 mm, 1.25 mm and 5 mm. The properties of coarse aggregate and fine aggregate are presented in Table 1.

| No | Testing items                        | Unit | C1   | C2   | C3   | D1   | D2   |
|----|-------------------------------------|------|------|------|------|------|------|
| 1  | Apparent specific gravity           | g/cm³| 2.66 | 2.65 | 2.65 | 2.85 | 2.85 |
| 2  | Bulk specific gravity (SSD)         | g/cm³| 2.64 | 2.64 | 2.64 | 2.84 | 2.84 |
| 3  | Bulk specific gravity (Dried)       | g/cm³| 2.62 | 2.63 | 2.63 | 2.80 | 2.80 |
| 4  | Bulk density                        | kg/m³| 1,449| 1,445| 1,445| 1,394| 1,408|
| 5  | Water Absorption                    | %    | 0.4  | 0.2  | 0.2  | 0.5  | 0.5  |
| 6  | Voids                               | %    | 45   | 45   | 45   | 50   | 50   |
| 7  | Content of mud, dust, clay          | %    | 0.7  | 0.5  | 0.5  | -    | -    |
| 8  | Maximum particle size               | mm   | 0.63 | 1.25 | 5.00 | 10.00| 20.00|

Test method of properties materials and concrete mixtures are tested according to Vietnamese National Standards (TCVN). The properties of EPS aggregates including bulk density, density and voids were tested using the same method as study [2].

3. Results and discussion
As stated, SPC is made by adding a certain amount of EPS aggregates into matrix. The amount of material is calculated on the density of concrete mixture and properties of materials. In the study, the concrete mixing is shown in Table 2.

The compressive strength of SPC depends not only on the strength of EPS aggregates, the density of SPC but also on the compressive strength of the matrix. Study on the effect of the compressive strength was performed on the N5, N6 matrix. N5, N6 have the same aggregate components, additives, water, but a part of cement has been replaced by limestone powder with the same fineness is 10%, 25% of the amount
used to the matrix achieve compressive strength respectively 61.5 MPa, 42.3 Mpa. The samples were made with density of from 1,400 to 2,000 kg/m³. The relationship between compressive strength and density of SPC is shown in Figure 2. Based on the test results, the regression equation has been developed, from which the chart shown in Figure 3 is built.

| No | Aggregate | Amount of material | Density, kg/m³ | Slump, mm | Compressive strength, MPa |
|----|-----------|--------------------|----------------|----------|--------------------------|
|    | Fine C, W, Sand, Coarse, SF, SP, MC, Lime stone powder |                      |                |          |                          |
| N1 | C1        | - 793 309 970 - 79.3 1.0 0.15 - | 2,160 220 | 82.0     |
| N2 | C2        | - 768 299 938 - 76.8 1.0 0.15 - | 2,090 210 | 82.5     |
| N3 | C3 D1     | 595 231 727 660 59.5 1.0 0.15 - | 2,280 205 | 79.2     |
| N4 | C3 D2     | 597 232 730 663 59.7 1.0 0.15 - | 2,290 205 | 81.1     |
| N5 | C1        | - 713 309 970 - 79.3 1.0 0.15 80 | 2,150 215 | 61.5     |
| N6 | C1        | - 593 309 970 - 79.3 1.0 0.15 200 | 2,120 220 | 42.3     |

**Figure 2.** Relationship between compressive strength and density

Research has shown that reduction rate compressive strength while reduce density of SPC base on high compressive strength matrix is lower than those of concrete with low compressive strength matrix. This result shows that the strength of the wall created by the matrix is important to ensure the compressive strength of SPC. This result is also consistent with the theory of concrete.

On the other hand, correlation of compressive strength between SPC and matrix also shows the significant impact of EPS aggregates, with characteristic of negligible compressive strength, has a great influence, making reducing compressive strength of SPC. Lines showing the relationship of compressive
strength at all density are below the median of the graph. This is significantly different from conventional normal concrete or expanded clay aggregate concrete.

The test results show that compressive strength of SPC is firstly affected by the density (Figure 4). The decrease of compressive strength is not linear law, but in a curve with large changes when the density is less than 1,600 kg/m³. The degree of reduction at N4 using aggregates D2 is twice as large as N2 using aggregate C2. This proves that the compressive strength of SPC depends not only on density but also on the maximum particle size aggregate of matrix.

Figure 3. Relationship between compressive strength of structural polystyrene concrete and matrix.

This study used N1, N2, N3, N4 (Table 1) with maximum particle size aggregate of matrix of 0.63 mm, 0.125 mm, 10 mm, 20 mm to consider the influence of aggregate in matrix to compressive strength of SPC. SPC mixture after adding a predetermined amount of EPS, was determined workability, density and compressive strength. Based on these data, the study established a regression equation showing the correlation between the maximum particle size of aggregate in the matrix and the SPC. The strength of polystyrene concrete decreases if the maximum particle size in the matrix increases. When diluting the concrete with expanded polystyrene, these particles are distributed evenly in the mortar phase between coarse aggregate particles with N3 or N4.
When the amount of EPS is enough, the binder is not enough to cover the surface of aggregate including coarse aggregates, sand, EPS. The structure of the polystyrene concrete has significant changes shown in the binder stone structure becomes discontinuous. At this time, the compressive strength of polystyrene concrete plummeted. With N1, N2 matrix (Table 1), the compressive strength of polystyrene concrete still maintains well at low density.

The influence of the maximum particle size in the matrix on the compressive strength of polystyrene concrete is similar to the results of the workability study and the stratification of the concrete mixture presented [4]. This is because the amount of cement paste in the matrix is larger than in SPC. The ratio of cement paste in SPC is smaller than in the matrix. the reduction in density is proportional with the reduction of paste. Because EPS has high elasticity and low compressive strength, the compressive strength of the SPC depends heavily on the strength and structure of the area associated with the matrix. When reducing the density, the thickness of this bonding area decreases, greatly affecting the compressive strength of SPC.
4. Conclusion

Based on results of the study, the following conclusions can be made:
- The ratio volume of matrix is the main factor effect on the compressive strength of structural polystyrene concrete. The compressive strength of structural polystyrene concrete decreases as the ratio volume of matrix.
- The reduction of compressive strength depends on the maximum particle size of aggregate in the matrix. At the same strength of matrix, the smaller the maximum particle size of aggregate in the matrix, the lower the reduction of compressive strength. The degree of reduction of compressive strength at N4 platform using D2 aggregate (D_{max} 20) is twice as large as N2 using C2 aggregate (D_{max} 1.25).
- At the same density, the compressive strength of structural polystyrene concrete is significantly reduced when the maximum particle size of aggregate in the matrix is larger than 10 mm.

References
[1] IU. M. Bazenov, Bạch Đình Thiên, Trần Ngọc Tính (2005), Công nghệ bê tông, NXB Xây dựng.
[2] Nguyễn Tiến Dích (2004), Báo cáo tổng kết đề tài “Nghiên cứu sử dụng vật liệu nhẹ cho nhà và công trình”- Mã số RDN 06 – 01, Viện KHCNXD.
[3] Hoàng Minh Đức, Lê Phương Ly, Nghiên cứu ảnh hưởng của một số yếu tố đến tính công tác và độ phân tầng của hỗn hợp bê tông polystyrene kết cấu, Tạp chí KHCN Xây dựng số 1/2018.
[4] Chen B, Liu J, Mechanical properties of polymer-modified concretes containing expanded polystyrene beads, Construction and Building Materials; Volume 21, Issue 1, Pages 7-11.
[5] Le Roy R, Parant E, Boulay C (2005), Taking into account the inclusions’ size in lightweight concrete compressive strength prediction. Cem Concr Res; 35:770–5.