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Combined Effects of Bottom Ash and Expanded Polystyrene on Light-weight Concrete Properties

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Abstract. The benefits of using waste materials as a partial replacement for cement in high performance concrete are also discussed. This paper presents the combined effects of bottom ash TPP "Vung Ang" and expanded polystyrene aggregate on different the properties of light-weight concrete. Twenty different concrete mixtures with a water to cement ratio of 0.4 and superplasticizer to cement ratio of 0.015 were used. On the one hand, the EPS was partially replaced with (0 ÷ 40)% by volume of concrete mixture. On the other hand, the fine aggregate was replaced with (0 ÷ 30)% by mass of BA TPP "Vung Ang". The engineering properties, including workability, density and compressive strength of light-weight concrete were investigated at different curing times. The level of decrease in the strength depends upon the replacement level of EPS and BA. Specifically, the concrete containing 40% EPS and 30% BA at 28 days of age decrease in average density and strength were 43.2% and 26.4%, respectively, in comparison with the control concrete.

1 Introduction

Recent years in Vietnam, with the recent rapid developments of High-Rise buildings in urban areas, larger and longer spanning concrete structures, better concrete performance with higher strength, lower density, low thermal conductivity and other properties is urgently required. Light-weight concrete has been used for structural purposes to meet these requirements and become an environmentally-sustainable material [1, 2].

Among the various types of light-weight concretes that have been proposed, those obtained by mixing high-performance cement-based composites with expanded polystyrene (EPS) are particularly interesting for their excellent properties, such as the ability to be fabricated on the construction site and the tailoring of properties by varying mineral additives and superplasticizers, as well as good energy-absorbing characteristics [3].

As we know, EPS aggregate is a light-weight material. Therefore, it can be partially replaced volume of concrete mixture to produce light-weight concrete, which is an important material in reducing the dead-weight of concrete complying with special concrete structures of high-rise buildings [4, 5].

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In addition, some studies [6, 7] have reported the importance of using fly ash, rice husk ash and bottom ash in concrete which can save a significant amount of energy and cost in cement manufacturing and also it can improve engineering properties of concrete by replacing with normal cement.

Besides that, the annual amount of industrial waste is more than 150 million tons in Vietnam. In which, metallurgical slag is about 45 ÷ 55 million tons, ash and slag TPP is nearly 50 ÷ 60 million tons [8, 9]. In 2016, TPP "Vung Ang" produces about 3000 tons of ash and slag waste daily. In addition, an enormous number of gaseous substances and solid particles formed as a result of solid fuel combustion enter the atmosphere through the smokestacks of this power plants, which have caused seriously environmental pollution in Vietnam central provinces.

Because the aim of this study was to investigate the combined effects of bottom ash TPP "Vung Ang" and expanded polystyrene aggregate on the properties of light-weight concrete, which are intended for light-weight concrete blocks with low thermal conductivity in the High-Rise Construction.

2 Experimental details

1.1 Materials

1. Good quality river sand was used as a fine aggregate, which produced from the quartz sand (QS) of "Lo River" (Vietnam). The fineness modulus M_K = 3.1, specific gravity and dry density are 2.65 g/cm^3 and 1650 kg/m^3. The particle size distributions details of fine aggregates is shown in Figure 1

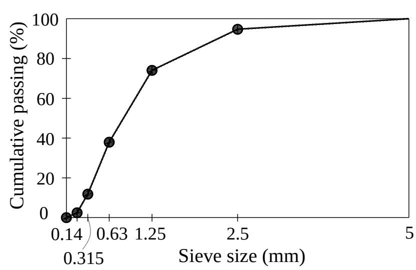


Fig. 1. Sieving analysis of good quality river sand

2. The cement used was ordinary Portland cement (OPC) (40 Grade), manufactured at "Tam Diep" factory (Vietnam), specific weight of 3.14 g/cm^3. The experimental results of physical and mechanical properties of cement are presented in Table 1 and the results of the chemical compositions are presented in Table 2.

Table 1. Physical and mechanical properties of ordinary Portland cement

Specific weight (g/cm^3)	Retained content on sieve 0.09 mm (%)	Surface area (cm^2/g)	Time of setting (min)		Compressive strength (MPa)			Standard consistency (%)
			Initial	Final	3 days	7 days	28 days	
3.14	5.15	3620	125	360	20.4	35.2	50.4	29.5

3. Bottom Ash (BA) TPP "Vung Ang" (Vietnam) Class F with specific weight of 2.22 g/cm^3, the volume of natural porous state are 860 kg/m^3 and water demand of 27.8%. Retained content on sieve 0.09 mm is 10.5%. The analysis results of chemical compositions of bottom ash TPP "Vung Ang" are presented in Table 2 and figure 2.

Table 2. Chemical properties of ordinary Portland cement and bottom ash TPP "Vung Ang"

Materials	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	LOI[(a)]	other
Portland cement	20.5	4.4	5.2	61.3	2.5	3.7	2.1	0.3
Bottom Ash	62.5	14.1	8.5	3.2	4.1	1.7	3.4	2.5

<u>*Note:*</u> *[(a)]LOI - Loss on ignition.*

4. Expanded polystyrene (EPS) was used as a light-weight aggregate with the size of 2.5 ÷ 5 mm. Its dry density is 20.5 kg/m^3 (figure 3).

5. Superplasticizer SR 5000F "SilkRoad" (SR5000) (Korea). It is a new generation chemical additives based on polycarboxylate ethers with specific weight of 1.1 g/cm^3 at 20 ± 5°C.

6. Ordinary clean tap water (W) was used for both mixing concrete and curing of test specimens.

2.2 Methods

On the one hand, this paper will analyze the chemical composition and the grain composition of bottom ash TPP "Vung Ang" by laser granulometry method. On the other hand, calculation method of concrete mixture composition is applied in accordance with absolute volume method. The flow ability of concrete mixture is determined by standard slump cone with dimensions of 100x200x300 mm. The compressive strength of light-weight concrete is determined by a 70x70x70 mm cube specimen by Russian standard GOST 10180-2012 at the ages of 3, 7, 14 and 28 days (Figures 4 and 5). These cube samples are demolded after 24 hours later casting and placed in a 20 ^{0}C water curing tank until the experiments. Besides, the dry density of concrete is determined by standard BS EN 12390-7:2009.

Fig. 2. Bottom ash TPP "Vung Ang"

Fig. 3. Expanded polystyrene

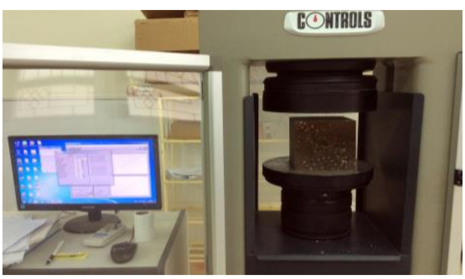


Fig. 4. Failure of concrete specimen under compression

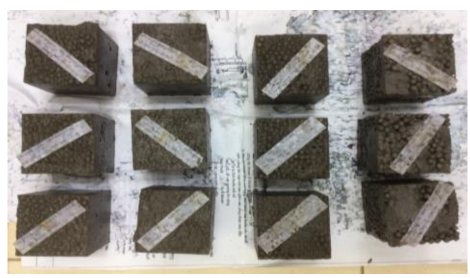


Fig. 5. Specimens of light-weight concrete

2.3 Concrete Mixtures

It is necessary to determine the concrete mixture compositions for the light-weight concrete production, which are intended for light-weight concrete blocks with low thermal conductivity in the High-Rise Construction in Northern Vietnam.

The initial ratios of raw materials by weight in concrete mixtures for the production of light-weight concrete are given in Table 3.

Table 3. Ratios of raw materials used in preliminary composition

Ratios	$\frac{W}{OPC}$	$\frac{QS}{OPC}$	$\frac{SR5000}{OPC}$	Volume of air in concrete
Value	0.4	1.4	1.5%	2%

Note: BID – bind: BID = PC + BA

Based on the rate on and combined with methods could work absolute, the preliminary of the material compositions in the dry state of the concrete mixture (control mixture) is shown in Table 4.

A total of twenty concrete mixtures with varying amounts of EPS and BA were made for this experiment. The control concrete mixture (mix. 1) had a proportion as in table 3.

On the one hand, the volume fresh concrete was replaced with 0%, 10%, 20%, 30% and 40% by volume of EPS aggregate. On the other hand, the fine aggregate was replaced with 0%, 10%, 20% and 30% by mass of BA TPP "Vung Ang".

According to [4, 5], choosing lower substitutions of EPS in concrete mixture is within satisfactory limits. However, one of the main goals of the present work is to utilise as much EPS aggregate as possible, solving the disposal problem of waste expanded polystyrene foam and producing light-weight concrete blocks with low thermal conductivity in construction the High-Rise buildings.

The ratios $\frac{W}{OPC}$ and $\frac{SR5000}{OPC}$ of 0.4 and 0.015 respectively were kept constant for all mixtures and no adjustment to the water content was made for all mixtures. In this study, the superplasticizer SR 5000F "SilkRoad" has been used to reduce the $\frac{W}{OPC}$ ratio and to increase workability of concrete mixtures. Details about all concrete mixtures used in this work can be found in Table 4.

Table 4. Mix compositions and properties of fresh concrete

Mix No.	EPS (%)	BA (%)	Compositions of concrete mixture (kg/m^3)						Properties of fresh	
			OPC	BA	SR5000	QS	W	EPS	Average density (kg/m^3)	Slump (mm)
1	0	0	781	0	11.7	1094	313	0	2200	125
2	0.1	0	702	0	10.5	983	281	2.05	1979	130
3	0.2	0	623	0	9.3	872	249	4.1	1757	145
4	0.3	0	543	0	8.2	761	217	6.15	1536	180
5	0.4	0	464	0	7	650	186	8.2	1315	185
6	0	0.1	781	98	11.7	983	313	0	2187	108
7	0.1	0.1	702	88	10.5	883	281	2.05	1967	125
8	0.2	0.1	623	78	9.3	783	249	4.1	1747	162
9	0.3	0.1	543	68	8.2	683	217	6.15	1527	154
10	0.4	0.1	464	58	7	584	186	8.2	1307	165
11	0	0.2	781	178	11.7	892	313	0	2176	92
12	0.1	0.2	702	160	10.5	801	281	2.05	1957	110
13	0.2	0.2	623	142	9.3	711	249	4.1	1738	145
14	0.3	0.2	543	124	8.2	620	217	6.15	1520	150
15	0.4	0.2	464	106	7	530	186	8.2	1301	156
16	0	0.3	781	245	11.7	817	313	0	2167	85
17	0.1	0.3	702	220	10.5	734	281	2.05	1949	102
18	0.2	0.3	623	195	9.3	651	249	4.1	1731	110
19	0.3	0.3	543	170	8.2	568	217	6.15	1513	121
20	0.4	0.3	464	146	7	485	186	8.2	1295	128

3 Test results and Discussion

3.1 The workability of concrete mixture

The slump cone values of the fresh concretes containing varying amounts of EPS aggregates and BA are presented in Table 4. The slump values were between 85 and 185 mm.

The workability of concrete mixtures containing 0% EPS (mixtures No.1, 6, 11 and 16) werein the range of 85 ÷ 125 mm and satisfying, and processes of casting, compaction, curing and finish-ability were performed easily. By increasing the EPS content, the workability of concrete mixtures increased. The increasing of consistency continued up to 40% EPS content. This was mainly due to EPS particles are hydrophobic and resist absorption of the mixture's water. It is also partly due to the influence of the use of the superplasticizer SR 5000F "SilkRoad".

The slump values were in the range of 125 ÷ 185 mm for concrete without BA and decreased to the range of 85 ÷ 128 mm with 30% BA. According to [2, 4], the concrete containing BA will cause an increase in consistency at a constant $\frac{W}{OPC}$ ratio. However, the fine aggregate was replaced with 0%, 10%, 20% and 30% by mass of BA TPP "Vung Ang", which has more surface area and porosity and increases the water demand, the fresh concretes' slump values decreased with an increase in bottom ash.

3.2 Effect of EPS and BA on density of light-weight concrete

The density of light-weight concretes complied with BS EN 12390-7:2009 containing different contents of EPS and BA is presented in Table 5 and Figure 5. The density values were in the range of 1235.4 ÷ 2188.9 kg/m^3.

Table 5. Density of light-weight concretes

Mix No.	EPS (%)	BA (%)	Density of concrete at 28 days (kg/m^3)		
			1	2	3
1	0	0	2180.6	2186.5	2188.9
2	0.1	0	1955.2	1960.7	1958.3
3	0.2	0	1725.6	1731.5	1728.4
4	0.3	0	1520.3	1518.5	1516.7
5	0.4	0	1285.6	1280.9	1281.3
6	0	0.1	2155.5	2161.7	2168.4
7	0.1	0.1	1951.3	1942.7	1948.8
8	0.2	0.1	1715.6	1711.9	1722.8
9	0.3	0.1	1500.4	1508.3	1502.9
10	0.4	0.1	1256.8	1261.7	1260.1
11	0	0.2	2145.10	2137.80	2142.6
12	0.1	0.2	1940.20	1935.60	1932.9
13	0.2	0.2	1710.50	1708.40	1705.7
14	0.3	0.2	1495.70	1492.40	1490.7
15	0.4	0.2	1252.80	1250.90	1251.6
16	0	0.3	2134.60	2142.70	2145.1
17	0.1	0.3	1923.50	1927.30	1918.6
18	0.2	0.3	1695.20	1699.70	1700.1
19	0.3	0.3	1475.60	1478.40	1480.2
20	0.4	0.3	1245.70	1242.60	1235.4

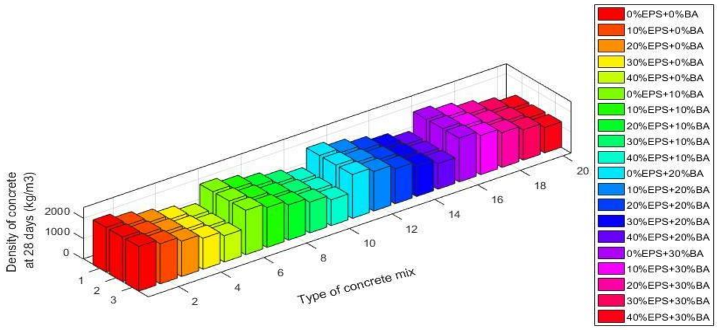


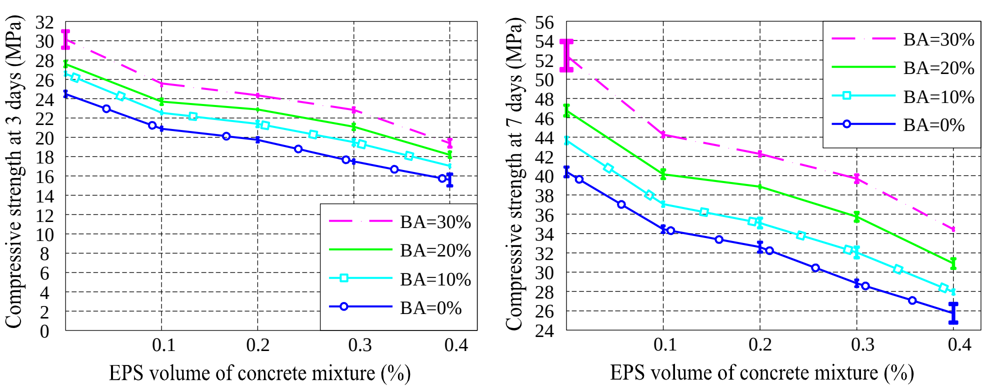
Fig. 5. Density of light-weight concrete at 28 days

The density values in Table 5 and Figure 5, shows that the density of concretes decreased with increasing in EPS contents in types of concrete. This is because the density of EPS aggregates was much less than that of natural aggregates (Table 2). According to Russian standard GOST 25820-2014, light-weight concrete is the concrete with a dry density between 500 and 1800 kg/m^3. Thus, in the case of present investigation the concrete incorporating 20% EPS by volume concrete mixture and higher can be considered as light-weight concrete.

Increasing the replacement level of BA with fine aggregate had little effect on the density of concretes. The density of light-weight concretes appears to decrease with an increase in the BA content. Specifically, the density of control mixture (0% EPS + 0% BA) was 2188.9 kg/m^3, which decreased to 2145.1 kg/m^3 with 30% BA content in concrete. A recent study [10] observed that the low density of light-weight concrete containing BA is probably related to the higher air content and lack of structure of BA.

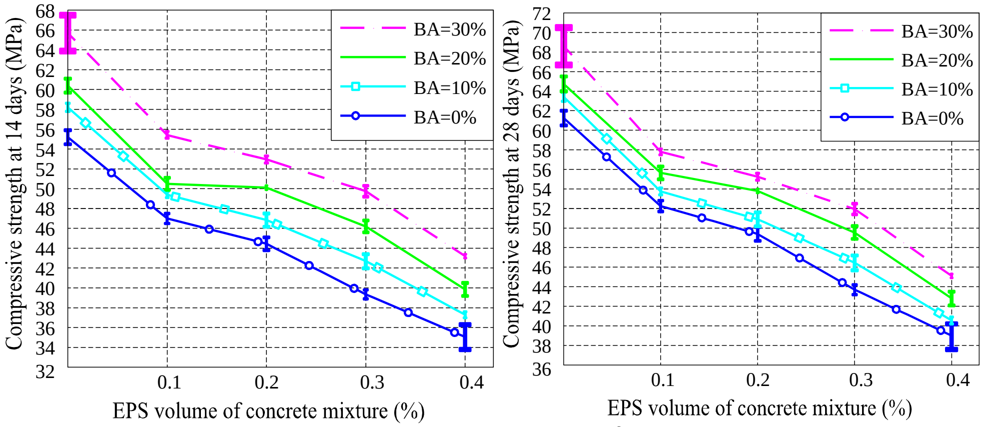
3.3 Effect of EPS and BA on compressive strength of concrete

The compressive strength of concretes containing varying amounts of EPS and BA at different curing times is shown in Table 6 and illustrated in Figure 6 and 7. The compressive strength was in the range of 15.4 ÷ 31 MPa at 3 days curing time and 37.6 ÷ 70.5 MPa at 28 days curing age.



a). Strength of concrete at age 3-days b). Strength of concrete at age 7-days

Fig. 6. Effect of EPS and BA on concrete compressive strength at ages 3 and 7 days



a). Strength of concrete at age 14-days
b). Strength of concrete at age 28-days

Fig. 7. Effect of EPS and BA on concrete compressive strength at ages 14 and 28 days

Table 6. Compressive strength of concrete at different curing ages

Mix No.	EPS (%)	BA (%)	Compressive strength concrete (MPa)											
			3 days			7 days			14 days			28 days		
1	0	0	24.2	24.8	24.5	39.9	40.9	40.4	54.5	55.8	55.1	60.5	62.0	61.2
2	0.1	0	21.1	20.7	20.8	34.8	34.1	34.4	47.5	46.5	46.9	52.8	51.7	52.1
3	0.2	0	19.5	19.7	20.0	32.1	32.5	33.1	43.8	44.4	45.1	48.7	49.3	50.1
4	0.3	0	17.3	17.7	17.6	28.5	29.2	29.0	38.9	39.8	39.5	43.2	44.2	43.9
5	0.4	0	15.4	15.0	16.2	25.3	24.8	26.7	34.6	33.8	36.4	38.4	37.6	40.4
6	0	0.1	26.4	26.8	26.6	43.3	44.0	43.7	57.8	58.6	58.3	62.8	63.7	63.4
7	0.1	0.1	22.7	22.4	22.6	37.3	36.8	37.1	49.8	49.1	49.5	54.1	53.4	53.8
8	0.2	0.1	21.1	21.7	21.4	34.6	35.6	35.1	46.2	47.5	46.8	50.2	51.6	50.9
9	0.3	0.1	19.2	19.8	19.5	31.5	32.6	32.1	42.0	43.4	42.8	45.7	47.2	46.5
10	0.4	0.1	17.0	16.9	17.2	27.9	27.7	28.2	37.3	37.0	37.6	40.5	40.2	40.9
11	0	0.2	27.3	27.3	27.9	46.2	46.2	47.3	59.7	59.6	61.0	64.1	64.0	65.5
12	0.1	0.2	23.4	23.8	24.0	39.7	40.3	40.6	51.2	52.0	52.5	55.0	55.8	56.3
13	0.2	0.2	22.8	23.0	22.8	38.7	39.0	38.7	49.9	50.3	49.9	53.6	54.0	53.6
14	0.3	0.2	20.8	21.4	20.9	35.3	36.2	35.4	45.6	46.8	45.7	48.9	50.2	49.1
15	0.4	0.2	17.9	18.5	18.2	30.4	31.4	30.9	39.2	40.5	39.9	42.1	43.5	42.8
16	0	0.3	29.3	30.0	31.0	51.0	52.2	53.9	63.9	65.3	67.5	66.7	68.2	70.5
17	0.1	0.3	25.4	25.6	25.3	44.2	44.4	44.0	55.4	55.7	55.1	57.8	58.1	57.5
18	0.2	0.3	24.5	24.2	24.2	42.5	42.1	42.0	53.3	52.7	52.6	55.6	55.0	54.9
19	0.3	0.3	22.6	23.1	23.0	39.3	40.2	40.0	49.2	50.3	50.1	51.4	52.5	52.3
20	0.4	0.3	19.9	19.8	19.8	34.7	34.3	34.4	43.4	43.0	43.1	45.3	44.9	45.0

The compressive strength is decreased as the EPS aggregate content in concrete mixture is increased. For example, the average compressive strength for the control concrete (0% EPS + 0% BA) was 61.23 MPa at 28 days of age and this decreased to 38.8 MPa for the concrete containing 40% EPS + 0% BA at the same age; the decrease in strength was about 36,6%.

The lower strength of light-weight concretes may be due to two factors: the first factor may be the lack of natural coarse aggregate in the concrete, as an investigation [4] reported that the concrete mixes containing coarse aggregate showed an increase in strength and a slight increase in density. Another factor may be the replacement of volume concrete mixture with EPS and the resulting increase in the surface area of fine particles, which can lead to weakening of interfacial transition zones between the fine aggregate and the cement paste. It is well known that the density of concrete has a significant influence on its strength. The strength of light-weight concretes decreased with the decrease in density of the concrete, as expected.

In the results presented in the published studies [12, 13], showed that the strength of control and light-weight concretes decreased with an increase in BA content. But in this study with the ratios water/ordinary Portland cement of 0.4 and was kept constant for all mixtures and no adjustment to the water content was made for all mixtures. Further the fine aggregate was replaced with (0 ÷ 30)% by mass of BA TPP «Vung Ang» - active mineral additives. Therefore, when increase in BA content, the concrete compressive strength also increases, but not much else. The average strength for the control concrete (40% EPS + 0% BA) was 38.8 MPa at 28 days of age and this increased to 45.067 MPa for the concrete containing (40% EPS + 30% BA) at the same age; the increase percentage in strength was about 16%. The concrete containing high contents of EPS and BA can be used in light-weight concrete blocks with low thermal conductivity in the High-Rise buildings.

4 Conclusion

Experimental study was carried out in the laboratory of Hanoi University of Mining and Geology to find out the effect of expanded polystyrene and bottom ash TPP "Vung Ang" on the light-weight concrete properties. The absolute volume method was used to determine the concrete mixture compositions. Concrete mix containing (0 ÷ 40)% EPS by volume concrete mixture and (0 ÷ 30)% BA mass of fine aggregate were used in the study. The following conclusions are drawn from the experimental results:

1. By increasing EPS and BA in concrete the density and compressive strength decrease. The level of decrease in the strength depends upon the replacement level of EPS and BA. For example, the concrete containing 40% EPS and 30% BA at 28 days of age decrease in average density and strength were 43.2% and 26.4%, respectively, in comparison with the control concrete.
2. According to Russian standard GOST 25820-2014, in this investigation, the concrete incorporating 20% EPS by volume concrete mixture and higher can be considered as light-weight concrete.
3. The novel concrete produced in the present study can be used in light-weight concrete blocks with low thermal conductivity in the High-Rise buidings in Vietnam.

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