An Experimental Study of Reusing Coal Ash for Base Course of Road Pavement in Viet Nam

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ABSTRACT

To decreasing serious environment problems from thermal power plants, it is essential to reuse the coal ash (coal bottom ash, fly ash) in Vietnam. Thus, this article presents two series of experimental study on reusing coal ash in the laboratories for base course of road pavement. Firstly, the coal bottom ash was mixed with 3%, 5%, 7%, 9%, and 11% of cement. Secondly, The coarse aggregate was stabilized with a constant amount of 3% cement and 10%, 15%, 20% fly ash. A total of 283 specimens were tested to investigate the properties of these mixtures. These experimental tests aim to find the mixtures that it meet technical requirements including CBR test, the proctor compaction test, compressive strength test, resilient modulus test, and splitting tensile strength test. The experimental results shown that the mixture of coal bottom ash with 11% cement, 10% fly ash with coarse aggregate and 3% cement has qualified properties of base, sub – base course layer of road pavement. This is a scientific basic for reusing coal ash from thermal power plants in Viet Nam.

KEYWORDS: Coal bottom ash, fly ash, thermal power plant, compressive strength, resilient modulus strength, splitting tensile strength.

INTRODUCTION

The thermal power plants is now still playing an important role in the Vietnamese economy because of low investment cost and abundance material resources. There are 21 thermal power plants with a capacity of 13100 MW, consumed about 45 million tons of coal per year and discharged about 15.7 million tons of coal ash per year. According to the forecast, there will be 26 thermal power plants with a total capacity of 36000 MW, represent 46.8% of total electricity generation, consume 67.3 million tons of coal in 2020. In 2030, the total of coal thermal energy will be approximately 75,000 MW, produce 56.4% of total electricity generation and consume 171 million tons of coal. So, there are large amount of total coal ash, but the consumption of coal ash is only about 3-4 million tons/ year. The coal ash make serious problem such as atmospheric pollution, water pollution and land pollution. Thus, it is necessary to study how to use coal ash for sustainable development and environmental protection. Moreover, the use of coal ash is one of the major trends of finding sustainable solutions for construction materials which replacing nonrenewable aggregates[11].

Coal fly ash includes fly ash and coal bottom ash. Fly ash is a by-product of coal combustion from thermal power plants, captured at the top of the furnace and coal bottom ash collected at the bottom of furnaces[12]. The use of fly ash as replacing Portland cement has become popular today. From the state – art - review of 180 publications since 2000 in this work, fly ash is a complex material and can be beneficial to the durability and late – age strength of concrete[5]. Fly ash can be used in different fields such as building material, synthesis of zeololites, soil amendment, removing air pollutants, removing water pollutions and future application[9]. Bottom ash can be used as partial sand replacement in concrete for road construction, foundation material, noise barriers, aggregate and art supplies[18]. According to a review, the effect of use bottom ash as a replacement for sand were investigated by various experiment but the investigation on the use of bottom ash has been very limited[18]. Some researchers in laters, strength properties of concrete using bottom ash with addition of propropylene fiber, compressive and tensile strength of concrete containing coal bottom ash were studied[2] . Moreover, bottom ash can be used as fine aggregate in high performance concrete[14].

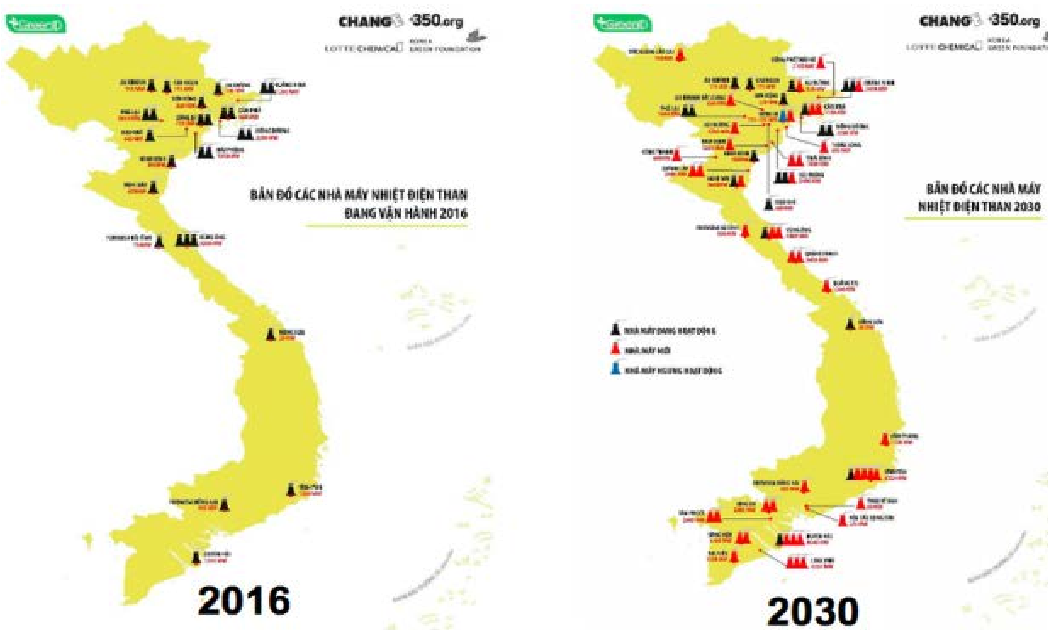

Figure 1: Vietnam's Planned Coal-Fired Plant Additions (Jill Baker, 2018)

A typical flexible pavement structure includes four components: asphalt, concrete layer; Base course layer; sub -base course layer; soft sub – grade layer or native soil[7] . Mixture fly ash – soil stabilization can be used for soft sub – grade layer which can achieve the requirement of compressive strength, modulus of elasticity[1][17] . High volume fly ash gypsum slurry with quarry are used in base/ sub -base pavement[13]. Mixture of soil, cement and fly ash has higher unconfined and lower hydraulic conductivity than the treat soil[10] . Fly ash affected in the sand compaction, the ratio of fly ash increases, maximum dry density decrease and optimum moisture content increases[16] .

Thus, in the world, there have been many researches on the use of fly ash for improving soil, bottom ash replacing aggregates in concrete. But, the properties of coal ash mainly depend on the type of coal and combustion conditions[9]. On the other hand, Vietnam has now 21 thermal power plants, including 7 plants which use a circulating fluidized bed combustion(CPB) with low-quality domestic coal, 14 thermal power plants use pulverized combustion (PC) with better quality domestic coal.

Moreover, fly ash – soi stabilization, coal bottom ash concrete is researched in many country such as American, India, Scandinavian, China. But, Mixture of coal bottom ash, mixuture of coarse aggregate – cement – fly ash is not applied. In Viet nam, there are limited in studying used fly ash, coal bottom ash in engineering construction. There are no reconmendations and regulation for coal bottom ash and fly ash in base/ sub – base course pavement.

Thus, the article studied is aimed at: Finding the new way of reusing coal ash in construction to reduce coal ash from thermal power plants, especially coal bottom ash which have not been reused in Vietnam; Researching and evaluating the technical properties of coal bottom ash - cement mixtures, coarse aggregate – fly ash - cement mixtures; Determining the optimal mixtures which meet the technical requirements for base, sub -base course layer of pavement structure.

MATERIALS AND METHODS

Materials

Materials used in this study include coal bottom ash, fly ash, Portland cement PCB 40 of VICEM Company and coarse aggregate. Coal bottom ash and fly ash was taken from An Khanh thermal power plant in Thai Nguyen province. The properties of cement, fly ash, coarse aggregate and coal bottom ash are summarized in **table.1**.

Table 1: Chemical composition, physico – mechanical properties of cement, coal ash and coarse aggregate

No	Properties		Fly ash	PCB 40	Coarse aggregate	Bottom ash
1	Chemical composition, %	MKN (%)	12.11	-		
		SiO_2	43.64	21.49		
		Fe_2O_3	8.71	3.30		
		Al_2O_3	20.05	5.00		
		SO_3	3.08	1.15		
		CaO	4.32	62.50		
		MgO	1.05	0.13		
		K_2O	2.27	0.75		
		Na_2O	0.22	0.26		
2	Specific gravity		2.21	3.10	2.66	2.48

3	Unit weight, kg/m^3		1070	1300	1370	1489
4	Compressive strength at 28 days curing, MPa			40		
5	Proctor compaction test					
	Maximum dry unit weight (MDD), g/cm^3				1.71	1.63
	Optimum water content (OMC), %				4.7	9.0
7	CBR test					
	CBR value (%)	K=1.00			129.18	51.6
		K=0.98			106.47	48.5
		K=0.95			129.18	42.4

From this table, fly ash classified Class F (ASTM C 618). Particle size distribution of bottom ash and coarse aggregate is shown in Figure 2 and Figure 3.

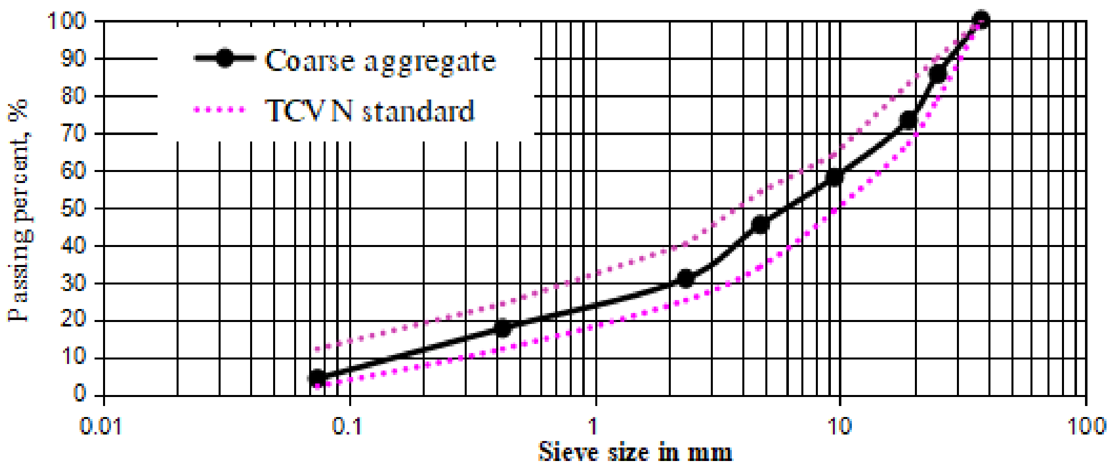

Figure 2: Particle size distribution of coarse aggregate

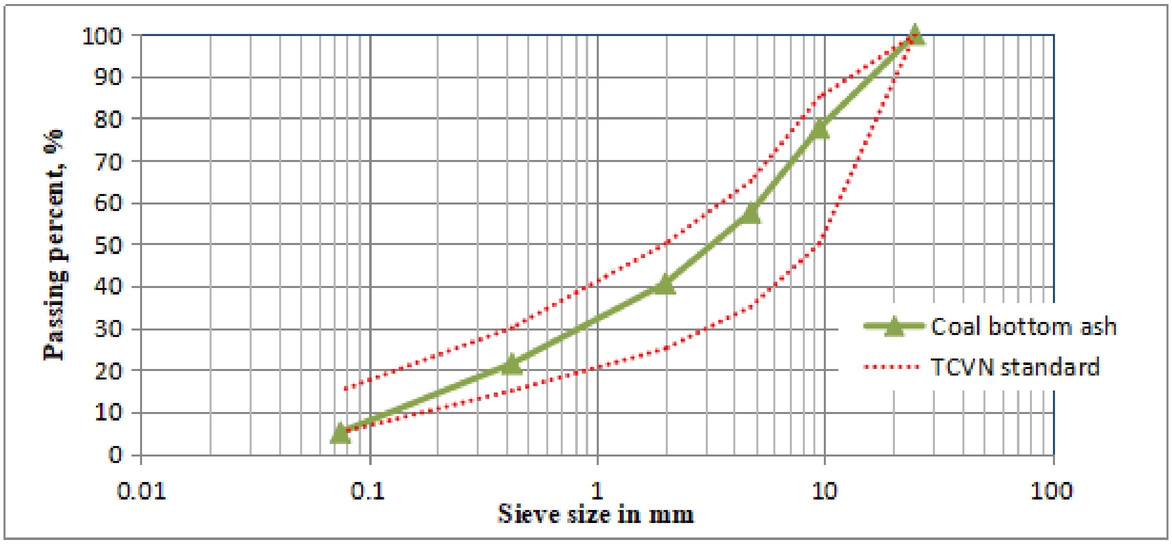

Figure 3: Particle size distribution of coal bottom ash

METHODS

(1) *Mixtures preparation*

In this study, two mixtures include the mixture I combining of coarse aggregate, cement and fly ash; the mixture II combining of coal bottom ash and cement.

Coal bottom ash is mixed with different percentage of cement (3, 5, 7, 9 and 11%) by dry weight of coal bottom ash. Coal bottom ash (CBA) – cement (CM) mixtures include: CBA+3%CM; CBA+5%CM; CBA+7%CM; CBA+9%CM; CBA+11%CM.

Fly ash is mixed with coarse aggregate and cement. The fly ash is 0, 10%, 15% and 20% by weight of dry coarse aggregate. Coarse aggregate (CA) – cement – fly ash mixtures includes: CA+3%CM; CA+3%CM+10%FA; CA+3%CM+15%FA; CA+3%CM+20%FA.

The properties of these mixtures were determined in optimum water content and dry unit weight conditions.

(2) *Proctor compaction test*

To determine optimum water content and dry unit weight, the proctor compaction test was carried out in accordance with Vietnamese standard 22TCN 332: 2206 which equivalent to ASTM D1557. Mixtures is prepared with water and incubated. The mixtures is placed in five layers in a cylindrical mold with 152mm in diameter and 117 mm in height, then compacted by 56 blows of a 44.48N rammer dropped from a distance of 457.2mm. After that, dry unit weight at selected molding water content is determined. From the relationship between water content and dry unit weight curve, optimum water content and dry unit weight are determined.

After that, the specimen was prepared to determine the technical properties of the mixture which include compressive strength, splitting tensile strength, resilient strength, and California bearing ratio properties. Mixtures samples were prepared at optimum water content and were compacted by proctor test.

The total number of prepared samples of mixture coal bottom ash and cement is 75 samples. There are 108 samples of mixture of coarse aggregate, cement and fly ash.

(3) Compressive strength test (ASTM D 1633)

After preparation, specimens were stored at humid room and were cured for 7, 14 and 28 days. Specimens are soaked in water for three days before testing. The compressive test were carried out by applying the load rate of 1mm/min until the specimens was destroyed.

(4) Splitting tensile strength test

After preparation, specimens were stored at humid room and were cured for 14, 28 days. Specimens are soaked in water for three days before testing. The splitting tensile strength test were carried out by applying the load a rate within the range of 0.1MPa/min to 0.7MPa/min until the specimens was broken.

The splitting tensile strength of the specimens calculates as follows:

$$T = 2P_{max}/pi()LD \qquad (1)$$

where:

T - splitting tensile strength, MPa;
P_{max} - maximum applied load indicated by the testing machine, N;
D - diameter of the specimen, mm;
L - length of the specimen, mm.

(5) Resilient modulus test

After preparation, specimens were stored at humid room and were cured for 7, 14 and 28 days. Before testing, the specimens were stored at humid room for 0, 7 or 21 days, then specimens were soaked for 7 days in the water. The resilient modulus test was carried out by applying the load rate of 3mm/min until the load of 20% compressive strength and the deformation are recorded (L1), then reduce the load and record and the deformation (L2) also recorded. The resilient modulus of materials calculates such ash:

$$E_{dh} = \frac{pH}{L} = \frac{4PH}{\pi D^2 L} \qquad (2)$$

where:

P - maximum applied load indicated by the testing machine, N;
p - compression pressure on the sample face, MPa;
H - sample height, mm;
D - sample diameter, mm;
L - elastic deformation of the material sample (L = L1-L2), mm;
$E_{đh}$ - resilient modulus of materials, MPa.

(6) California Bearing Ratio

Testing was carried out in accordance with 22TCN 335: 2006 which is equivalent to ASTM D 1183. Three specimens were prepared with compacting with 10, 30 and 65 blows per layer respectively. After compaction, specimens were stored at humid room and were cured for 28 days. The load is applying with the rate of penetration of 1.27mm/min. The CBR test specimen is to be soaked for 96 hour to determine percentage of swell. The CBR value is determined at 2.54mm or 5.08mm penetrations.

RESULTS AND DISCUSSION

Mixture of coal bottom ash and cement

The compacts results of coal bottom ash mixtures are shown in Figure 4. The results of maximum dry unit weight and optimum water content of mixture cement and coal bottom ash are summarized in Table 2. The result shown that the increase of cement content showed higher value of maximum dry unit weight and lower optimum water content. It is similar to the compaction test results of treated sub -base soil with fly ash and cement (M. Jayakumar at el., 2012). So, the coal bottom ash is type of sand soil. The highest maximum dry unit weight in this study is 1.74 g/cm^3 at optimum water of 7.0% in mixtures of coal bottom ash and 11% cement.

Table 2: Result of compaction test of coal bottom ash - cement mixtures

No	Types of mixtures	Maximum dry unit weight, g/cm^3	Optimum water content, %
1	CBA + 3% CM	1.64	8.0
2	CBA + 5% CM	1.66	7.6
3	CBA + 7% CM	1.68	7.4
4	CBA + 9% CM	1.73	7.2
5	CBA + 11% CM	1.74	7.0

Notes: CBA – Coal bottom ash; CM – Cement

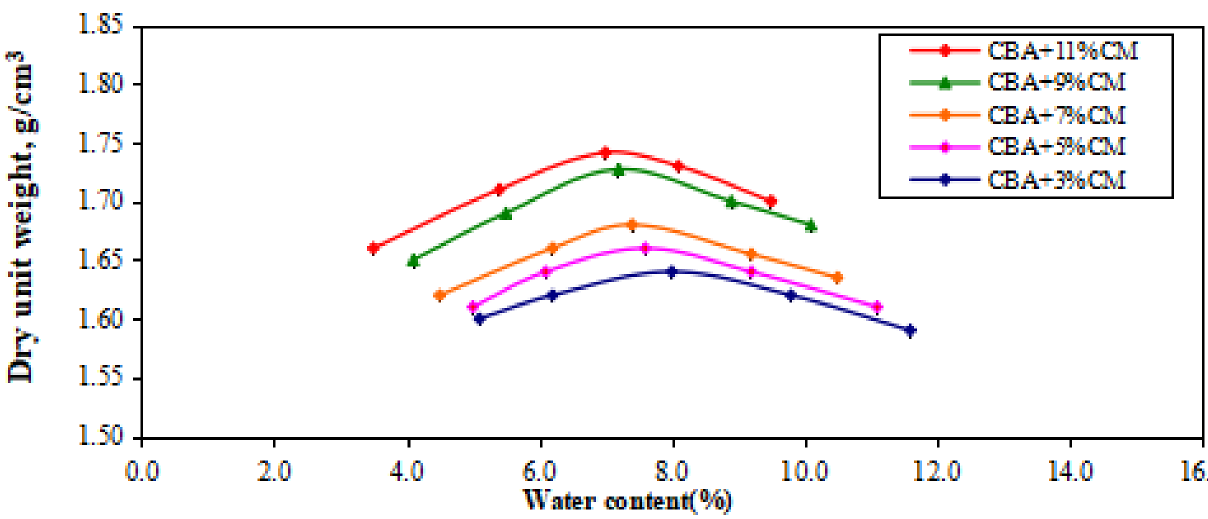

Figure 4: Water content – dry unit weight of coal bottom ash - cement mixtures

The result of compressive strength and determination of elastic modulus test are shown in fig.5, 6. Fig. 5 shows that compressive strength increase rapidly during 7 to 14 days curing, then increase slowly during 14 to 28 days. Compressive strength of mixtures at 7 and 14 days curing equals

43÷58%, 79÷94% of compressive strength of mixture at 28 days curing respectively. This result can be explained by the hydration of cement in mixtures. The minimum compressive strength 1.56 MPa at 28 days curing (for CBA+3%CM) meets minimum requirement of 1.0MPa for road pavement in accordance with Vietnamese standard TCVN 10186:2014. The results show that the strength and resilient modulus increase with increasing in percentage of cement content. The results are similar to the study of Shenbaga R. Kaniraj at el., 1999 on the strength and mixture of cement - fly ash and soil.

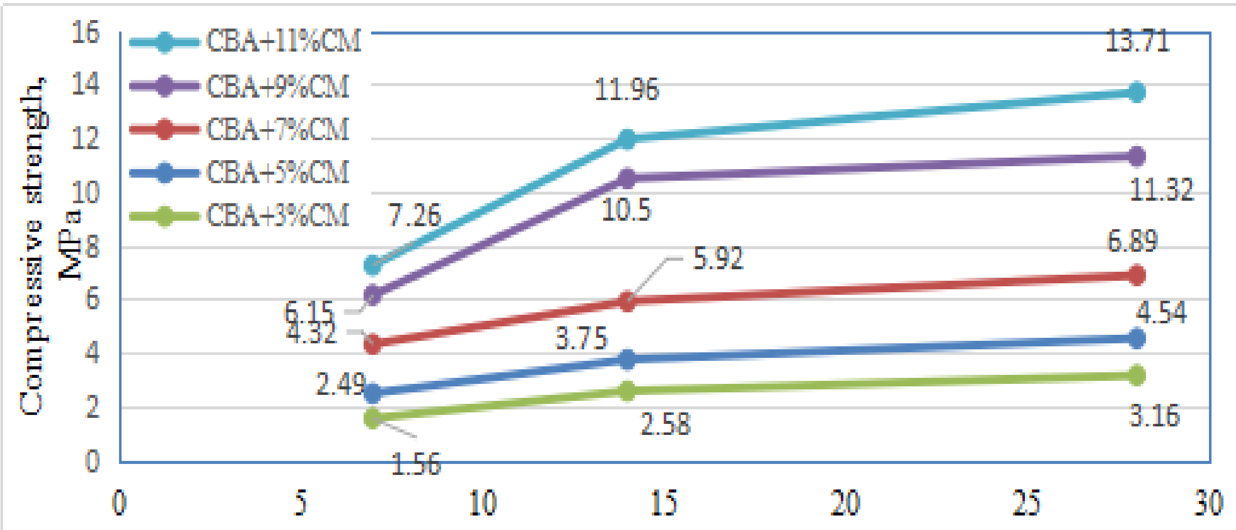

Figure 5: Compressive strength of coal bottom ash - cement mixtures

Figure 6 shows the resilient modulus of coal bottom ash – cement mixtures at 7, 14 and 28 days curing. The results shows that the mixtures has highest resilient modulus in mixtures of bottom ash and 11% cement by weight of dry bottom ash.

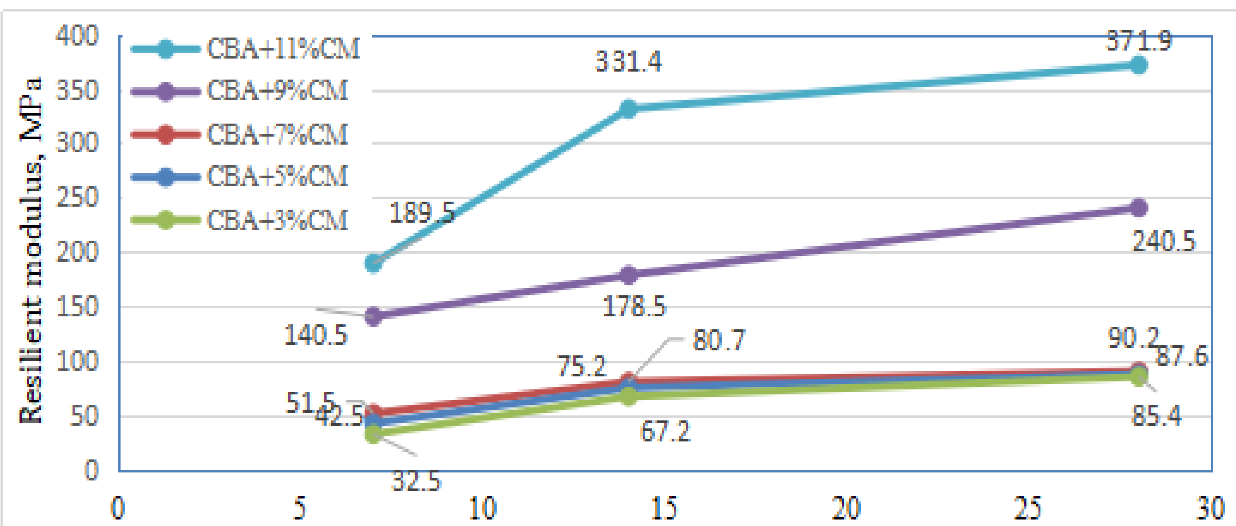

Figure 6: Resilient modules of coal bottom ash - cement mixtures

Fig.7 shows the results of determination of splitting tensile strength of 28 days curing. Splitting tensile strength of coal bottom ash - cement mixtures is small, ranges of 0.027 MPa to 0.133 MPa. The maximum splitting tensile strength of coal bottom ash -11% cement mixture meets minimum requirement of 0.12MPa in accordance with Vietnamese standard TCVN 10186:2014.

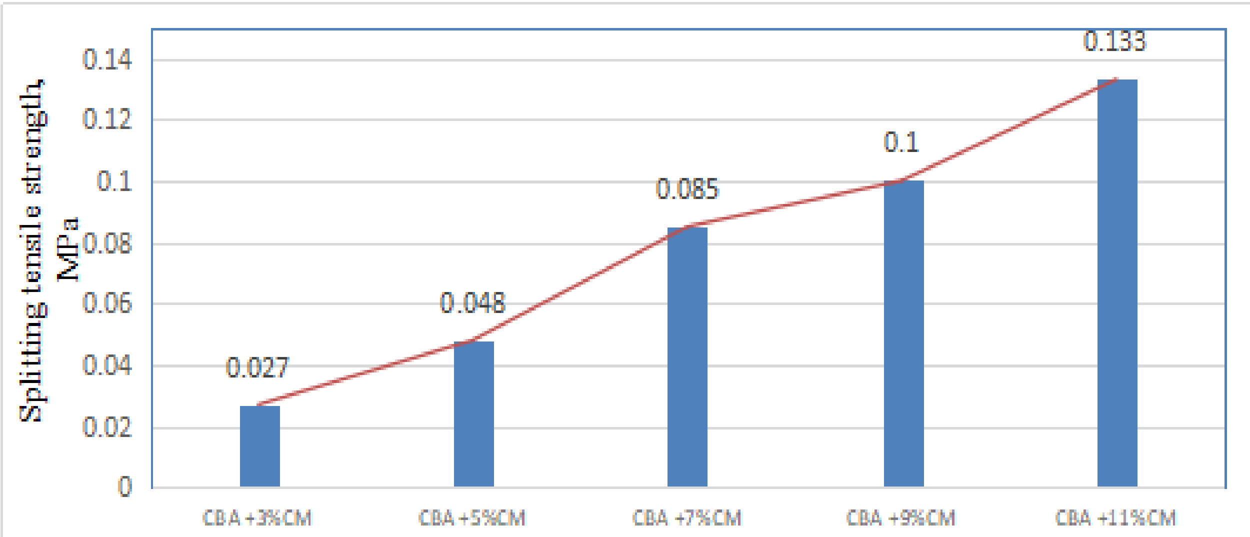

Figure 7: Splitting tensile strength of coal bottom ash - cement mixtures

The CBR test results are indicated in table.3. The CBR values of all mixtures have high values and is higher than the CBR value of coal bottom ash. The highest value of 208.17% at 28 days curing was obtained 11% cement mixing coal bottom ash. The high value was achieved by hydration cement.

Table 3: Result of California bearing ratio (CBR) test of coal bottom ash - cement mixtures

Types of mixtures	CBR test					
	Swell (%) at blows per layer			CBR (%) at		
	10	25	56	K=0.95	K=0.98	K=1.0
	%			%		
CBA + 3% CM	0.00	0.00	0.00	106.32	122.44	130.43
CBA + 5% CM	0.00	0.00	0.00	118.76	137.90	146.49
CBA + 7% CM	0.00	0.00	0.00	128.73	149.77	158.52
CBA + 9% CM	0.00	0.00	0.00	171.01	195.77	205.52
CBA + 11% CM	0.00	0.00	0.00	144.87	184.32	208.17

From these studies, coal bottom ash mixed 11% cement meet the requirement stipulated in Vietnamese standard 22 TCN 211-06 and TCVN 10186:2014.

Mixture of coarse aggregate, cement and fly ash

The dry unit weight and water content relationship of the coarse aggregate – fly ash – cement mixture is showed in Figure 8. The maximum dry unit weight and optimum water content of mixture cement and coal bottom ash are shown in Table 4. Maximum dry unit weight changes from 1.68 to 1.73 g/cm^3 and decreases with increasing of fly ash content. The results also shows that fly ash content increases, the optimum water content increases otherwise maximum dry unit weight decreases[4] . This result can be explained by the lightweight of fly ash and the maximum dry unit weight and optimum water content are directly dependent on the fly ash content[16].

Table 4: Result of compaction test

No	Types of mixtures	Maximum dry unit weight, g/cm^3	Optimum water content, %
1	CA +3%CM	1.73	5.0
2	CA +10% FA+3% CM	1.72	5.5
3	CA +15% FA+3% CM	1.70	6.0
4	CA +20% FA+3% CM	1.68	6.3

Note: CA – Coarse aggregate; CM – cement; FA- fly ash

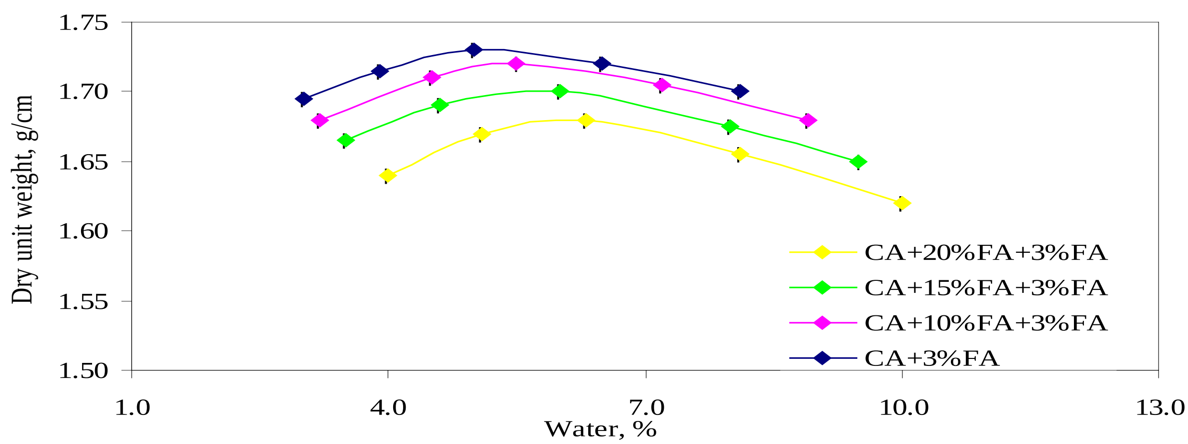

Figure 8: Water content – dry unit weight relationship of coarse aggregate - fly ash – cement mixtures

Figure 9 shows the compressive strength of 3% cement – (0, 10,15) 20% fly ash – coarse aggregate at different days curing. It can be seen that, the highest compressive strength at coarse aggregate – 3% cement – 10% fly ash mixtures. The compressive strength of mixture increase incase using fly ash, but compressive strength decreases in increasing fly ash content (at 15, 20% fly ash) or fly ash ratio. The mixtures of CA+10%FA+3%CM should be used for road construction. The minimum compressive strength 3.29 MPa at 14 days curing (for CA+20%FA+3%CM) meets minimum requirement of 1.5MPa for sub - base of road construction.

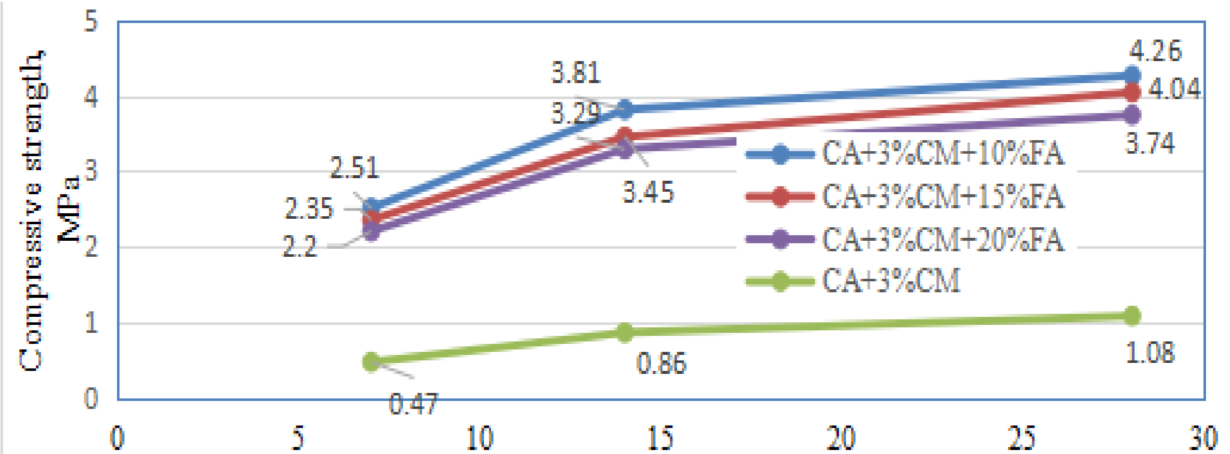

Figure 9: Compressive strength of coarse aggregate - fly ash – cement mixtures

The resilient modulus of coarse aggregate – fly ash – cement mixtures at 7, 14 and 28 days curing are shown in Figure 10. The results shows that the mixtures has highest resilient modulus if coarse bottom ash mixing 3% cement and 10% fly ash by weight of dry soil.

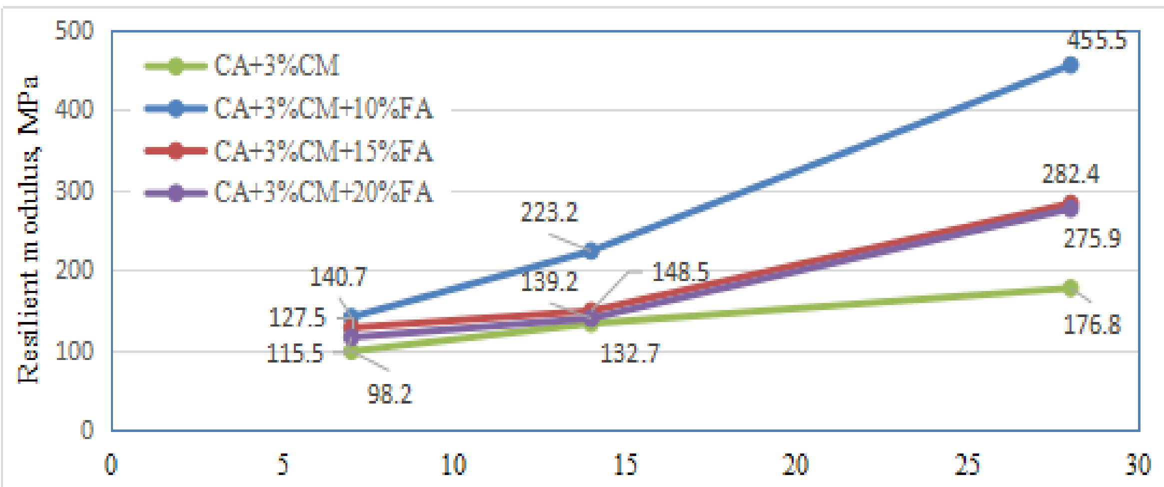

Figure 10: Resilient modulus of coarse aggregate - fly ash – cement mixtures

Fig.11 shows the results of determination of splitting tensile strength. Splitting tensile strength of coarse aggregate - cement mixtures is small, ranges of 0.006 MPa to 0.036 MPa at 14 days curing, ranges of 0.018 MPa to 0.061 MPa at 28 days curing. The highest of splitting tensile strength of coarse aggregate -10% fly ash – 3% cement mixture is 0.036 MPa at 14 days curing and 0.061 MPa at 28 days curing.

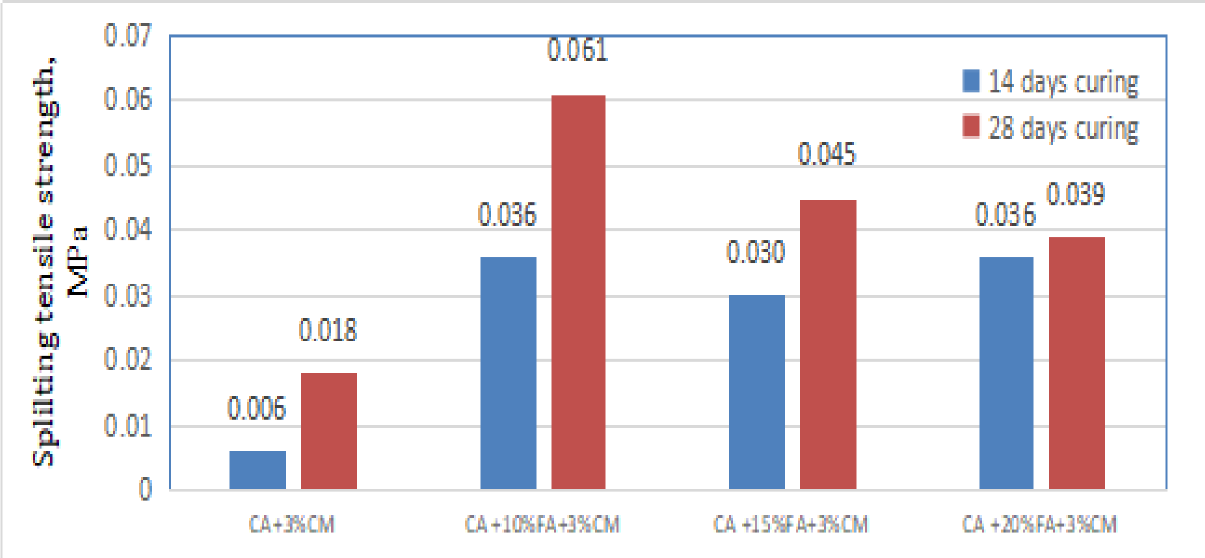

Figure 11: Splitting tensile strength of coarse aggregate - fly ash – cement mixtures

Table 5 indicates the CBR test results. The CBR values of all mixtures have high values. The highest value of 209.24% at 28 days curing was obtained 3% cement and 10% fly ash mixing coarse aggregate. The high value was achieved by hydration cement. The hydration of cement in mixtures forms calcium silicate hydrate gel and the more cement dosages form more hydrate gel that enhance continuous increment in CBR value[10].

Table 5: Result of California bearing ratio test of *coarse aggregate - fly ash – cement mixtures*

Types of mixtures	CBR test					
	Swell (%) at blows per layer			CBR (%) at		
	10	25	56	K=0.95	K=0.98	K=1.0
	%			%		
CA +3%CM	0.00	0.00	0.00	179.96	197.76	204.49
CA +10% FA+3% CM	0.00	0.00	0.00	186.90	205.40	209.24
CA +15% FA+3% CM	0.00	0.00	0.00	169.57	187.03	191.82
CA +20% FA+3% CM	0.00	0.00	0.00	140.69	164.79	175.41

Based on the results of this study, coarse aggregate mixed 3% cement with (10,15%), and 20% fly ash meet the requirement of base course pavement. It appears that coarse aggregate – fly ash – cement can be suitable for road construction.

CONCLUSIONS

(1) From the exprerimental study of miture of fly ash, cement and coarse aggregate, miture of fly ash bottom ash with cement, coal ash produced as waste materials can be a good construction material for road pavement.

(2) Fly ash in An Khanh thermal power plat can be classified of Class F with low Loss on Ignition and low SO3 content. It can be used in the mixture of coarse aggregate, fly ash and cement. The most mixture suitble for road pavement is coarse aggragate mixing with 5% cement and 20% fly ash.

(3) In case of mixture of coal bottom ash, the suitable of this is combining coal bottom ash with 11% cement.

(4) The development of compressive strength and resilent modulus is increasing with days curing due to the hydration products. It discovers that fly ash – cement – coarse aggregate mixtures, bottom ash - cement are suitable for use in road construction.

REFERENCES

[1] American Coal Ash Association (2003). Fly Ash Facts for Highway Engineers.

[2] A I F Ahmad Maliki, S Shahidan1, N Ali, N I R Ramzi Hannan, S S Mohd Zuki, M H W Ibrahim, M A Mohammad Azmi1 and M. Abdul Rahim (2017), Compressive and tensile strength for concrete containing coal bottom ash, IOP Conf. Series: Materials Science and Engineering 271 (2017).

[3] Dr. K. Chandrasekhar Reddy, K. Dharani (2017), Strength Properties of Concrete Using Bottom ash with addition of Polypropylene Fiber, International Journal of Advanced Information Science and Technology (IJAIST) ISSN: 2319:2682, Vol.6, No.7, July 2017.

[4] Fabio satos (2011). Geotechincal properties of fly ash and soil mixtures for use in higway embankments, journal of geotechnical and geoenvironmental engineering © ASCE / July 2005. DOL: 10.1061/(ASCE)1090-2041(2005)131:7(914).

[5] Gang Xu, Xianming Shi (2018). Characteristics and applications of fly ash as a sustainable construction material: A state-of-the-art review, Resources, Consevation and Recycling 136, 95-109.

[6] Harwalkar, A., Awanti, S. (2014). Laboratory and field investigations on high-volume fly ash concrete for rigid pavement. Transp. Res. Rec. 2441, 121–127.

[7] Hesham Ahmed Hussin Ismaiel (2006).Treatment and improvement of the geotechnical properties of different soft fine-grained soils using chemical stabilization, Shaker. Dissertation of doctor, Institute of Geology, Martin Luther Halle-Wittenberg University, Germany.

[8] https://www.forbes.com/sites/jillbaker/2018/05/21/this-clean-energy-champion-is-out-to-break-vietnams-coal-habit/#78c20abb476b

[9] Jun Cong Ge ,Sam Ki Yoon and Nag Jung Choi (2018), Application of Fly Ash as an Adsorbent for Removal of Air and Water Pollutants. Appl. Sci. 2018, 8(7), 1116.

[10] M. Jayakumar and Lau Chee Sing (2012), Experimental Studies on Treated Sub-base Soil with Fly Ash and Cement for Sustainable Design Recommendations, International Journal of Civil and Environmental Engineering, Vol:6, No:8.

[11] Marinković, S., Dragaš, J., Ignjatović, I., Tošić, N., 2017. Environmental assessment of green concretes for structural use. J. Clean. Prod. 154, 633–649. http://dx.doi.org/10.1016/j.jclepro.2017.04.015.

[12] Provis, J.L., Palomo, A., Shi, C., 2015. Advances in understanding alkali-activated materials. Cem. Concr. Res. 110–125.

[13] Revathi, V. (2009), Studies on the properties of High volume fly ash gypsum slurry With quarry waste and its use in Pavement base course, thesis of doctor of philosophy, Faculty of civil engineering Anna University Chennai.

[14] S. Loveley Kumari, T.S. Thandavamoorthy (2017), development of high performance concrete using bottom ash as fine aggregate, International Journal of Civil Engineering and Technology (IJCIET) Volume 8, Issue 12, December 2017, pp. 354–36.

[15] Shenbaga R. Kaniraj, Vasant G. Havanag (1999), Compressive strength of cement stabilized fly ash-soil mixtures. Cement and Concrete Research 29 (1999) 673–677.

[16] Siavash Mahvasha, Susana López-Querolb, Ali Bahadori-Jahromia (2017), Effect of class F fly ash on fine sand compaction through soil stabilization. Heliyon, Volume 3, Issue 3, March 2017.

[17] Tuncer. Edil, H. A. Acosta and C. H. Benson (2006). Stabilizing soft fine-grained soils with fly ash. Journal of Materials in Civil Engineering 18(2): 283-294.

[18] Vikas R Nadig at al., 2015, Bottom Ash as Partial Sand Replacement in Concrete- A Review, IOSR Journal of Mechanical and Civil Engineering. Volume 12, Issue 2 Ver. VI (Mar - Apr. 2015).

[19] TCN 211-06. Flexible Pavement – Design Requirements and Guideline.

[20] 22TCN 332: 2006. The California Bearing Ratio in Laboratory.

[21] 22TCN 333: 2006. Standard compaction test.

[22] AASHTO T 307 - Standard Method of Test for Determining the Resilient Modulus of Soils and Aggregate Materials.

[23] AASHTO T134, Standard Method of Test for Moisture-Density Relations of Soil-Cement Mixtures.

[24] ASTM C618 – 19. Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete.

[25] ASTM D1633 - Standard Test Methods for Compressive Strength of Molded Soil-Cement Cylinders. ASTM D1883- Standard Test Method for CBR (California Bearing Ratio) of Laboratory-Compacted Soils.

[26] 10302:2014. Activity admixture - Fly ash for concrete, mortar and cement.

[27] TCVN 10379: 2014. Soils stabilized with inorganic adhesive substances, chemical agent or reinforced composite for road construction - Construction and quality control.

[28] TCVN 7572:2-2006. Aggregates for concrete and mortar – Test methods -Part 2: Determination of particle size distribution.

[29] TCVN 8857: 2011. *Natural Aggregate for Road Pavement Layers Specification for Material, Construction and Acceptance.*

[30] TCVN 8858:2011. *Cement Treated Aggregate Bases for Road Pavement - Specification for Construction and Acceptance*.

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[32] Li Chong-mao, Nie Rui, Wang Jian-jun, Qian Xiang-yan, "The Planning of Coalmine Intelligent Management System Based on the Concept of 'Safety, Greenness and People-Orientation'," *The Electronic Journal of Geotechnical Engineering*, Vol. 20(19):11177-11184. Available at the website ejge.com.

[33] Hu Yong-zhong, Liu Chang-you, Li Jian-wei (2015) "Fractal Analysis of Cracks Due to Mixed Mining of Coal Seam Group" *The Electronic Journal of Geotechnical Engineering*, Vol. 20, Bund. 20(17):9749-9760. Available at ejge.com.

[34] Nian-chao Zhang, Nong Zhang, Hua-yang Wang, Bai-long Ma, Yuan-tian Sun, and Joan Esterle: "Floor Failure Depth of the Roadway in Soft Rocks of Deep Coalmine: A Case Study" *The Electronic Journal of Geotechnical Engineering*, 2016 (21.5). Available at ejge.com.

[35] Ang Li and Kaifeng Li: "Floor Water Inrush Risk Evaluation for Mining above Confined Aquifer in No. 5 Coal Seam of Taiyuan Group at Dongjiahe Coal Mine" *The Electronic Journal of Geotechnical Engineering*, 2016 (21.5): 1809-1822. Available at ejge.com.

[36] Wenbiao Sun: "The Ascending Mining Technology of Closed Multiple-Seams with a Large Mining Depth" *Electronic Journal of Geotechnical Engineering*, 2016 (21.19), pp 6337-6346. Available at ejge.com.

[37] Han Xiao-ming, Luo Chen-xu, Li Jia-liang, Wang Han: "Drilling Cuttings Migration Characteristics during Gas Extraction Borehole in Soft Coal Seam" *Electronic Journal of Geotechnical Engineering*, 2017 (22.08), pp 3049-3061. Available at ejge.com.

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