Effect of fly ash on the mechanical properties and drying shrinkage of the cement treated aggregate crushed stone

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Abstract. This paper presents the influence of fly ash on the mechanical properties and drying shrinkage of cement treated aggregate crushed stone (CTACS) mixture. The fly ash can replace 20-40% the weight of cement for the mixture of 4% CTACS, while it can supplement 3-9% the weight of aggregate crushed stone for both mixtures of 3% and 4% CTACS. Furthermore, the experimental findings indicated that the reduction in the compressive strength and the splitting tensile strength of CTACS was inversely proportional to the fly ash content replaced partially by the cement. However, the increase in the compressive strength and the splitting tensile strength of CTACS was directly proportional to the fly ash content. It was observed from the test results that the drying shrinkage of all mixtures was smaller than the control mixture without fly ash. The drying shrinkage of mixtures reduced inversely to the proportion of the fly ash content when 20-40% cement was replaced by the fly ash. When adding 3-9% fly ash, the 6% fly ash gave the smallest drying shrinkage.

Keywords: Aggregate crushed stone; cement and fly ash treated aggregate crushed stone; compressive strength; splitting tensile strength; drying shrinkage.

1 Introduction

Aggregate crushed stone (ACS), which is the most popular material, is often used in bases of pavement structure in Vietnam. However, under disadvantage conditions such as high category pavements having large traffic volumes or long-lasting wet subgrade and pavement, the strength of ACS is usually deteriorated, thereby resulting in the unstable pavement and the damage to surface course of flexible pavement such as rutting, cracking, potholes, etc. In order to improve the strength and stability of the ACS layer, the cement treated aggregate crushed stone (CTB) with the cement content from 3 to 8% by weight of dry ACS is commonly used. The high stiffness of CTB layer reduces the vertical deflection and tensile strain of the top layer materials. Besides, the failures of pavement such as cracks and potholes are reduced because CTB layer prevents moisture and stabilizes strength in wet conditions. In addition, subbase and subgrade failures are decreased because CTB spread traffic loads over wide areas and can span weak subgrade locations [1]. Although CTB showed many advantages,

C. Ha-Minh et al. (eds.), *CIGOS 2019, Innovation for Sustainable Infrastructure*, Lecture Notes in Civil Engineering 54,
https://doi.org/10.1007/978-981-15-0802-8_65

it required a high construction cost. Moreover, this structure exhibited the high drying shrinkage causing cracks, which can develop on the top layers and damage on the surface of asphalt layer. These cracks lead to damage of the structure and reduce service life of the pavement. Under the real condition, the CTB shows the large drying shrinkage due to the water evaporation. Previous studies [2, 3, 4, 5, 6, 7] illustrated that using a certain amount of fly ash (FA) can significantly reduce drying shrinkage of CTB structure.

This study carried out experiments to determine the mechanical properties and drying shrinkage over time of cement and fly ash treated aggregate crushed stone (CFATB) mixtures in the laboratory conditions up to 90 days. The results demonstrated the change of drying shrinkage of CFATB with curing time as well as the optimum value of fly ash.

2 Materials and methods

2.1 Materials

Aggregate crushed stone: Using Aggregate crushed stone type I, D_{max} = 25 mm in Danang. The particle size distribution, mechanical and physical properties of ACS are in accordance with Vietnamese standard TCVN 8859:2011 [8] as shown in Table 1.

Cement: Using 40 MPa grade Kimdinh Portland blended cement conform to Vietnamese standard TCVN 6260:2009 [9] and TCVN 8858:2011 [10].

Fly ash: Using fly ash (FA) of Nongson - Quangnam Thermal Power Plant. The physical properties and chemical compositions of FA follow to ASTM C618 [11].

Table 1. The particle size, mechanical and physical properties of aggregate crushed stone, D_{max} = 25 mm

The particle size distributions								
Sieve size (mm)	37.5	25.0	19.0	9.50	4.75	2.36	0.425	0.075
Passing Percentage (%)	100.0	86.9	72.6	56.1	41.3	31.1	16.6	5.7
Specification TCVN 8859:2011 (%)	100.0	79-90	67-83	49-64	34-54	25-40	12-24	2-12

The mechanical and physical properties			
Order	Specifications	Test results	Specification TCVN 8859:2011
1	Los Angeles (L.A) abrasion, %	27.9	≤ 35
2	CBR index, %	135.0	≥ 100
3	Liquid Limit, (%)	21.32	≤ 25
4	Plastic index, (%)	4.58	≤ 6
5	Elongation and flakiness index, (%)	12.4	≤ 15

2.2 Test methods

Proctor compaction test.
In this study, the mixtures using 3% and 4% cement by weight in combination with 3%, 6% and 9% FA by weight of dry ACS were chosen. Additionally, 20%, 30% and

40% of the cement were replaced by the fly ash for CFATB having 4% cement by weight.

The compaction test of CFATB mixtures was conducted according to Vietnam standard 22TCN 333-2006 after removing oversize particles on 19.0 mm sieve [12]. The mould is 152 mm in diameter and 117 mm in height, respectively. The weight of tamping rod is 4.5 kg and height of fall is 475 mm. Each testing sample was divided into 5 layers and each layer was compacted with 56 times. The optimal moisture content (W_0) and the maximum dry density (γ_{max}) of the CFATB mixtures are shown in Table 2.

Table 2. Mixtures proportions for 100 kg of dry ACS

Symbol	ACS (kg)	W (lit)	CM (kg)	FA (kg)	CM/ACS (%)	FA/ACS (%)	W/CM	W/B	FA/CM	W_0 (%)	γ_{max} (g/cm^3)
3CM0FA	100	5.69	3.0	0.0	3.0	0.0	1.90	1.90	0.00	5.52	2.32
3CM3FA	100	6.59	3.0	3.0	3.0	3.0	2.20	1.10	1.00	6.22	2.36
3CM6FA	100	7.44	3.0	6.0	3.0	6.0	2.48	0.83	2.00	6.83	2.34
3CM9FA	100	8.33	3.0	9.0	3.0	9.0	2.78	0.69	3.00	7.44	2.28
4CM0FA	100	5.90	4.0	0.0	4.0	0.0	1.47	1.47	0.00	5.67	2.35
4CM3FA	100	6.79	4.0	3.0	4.0	3.0	1.70	0.97	0.75	6.35	2.40
4CM6FA	100	7.67	4.0	6.0	4.0	6.0	1.92	0.77	1.50	6.97	2.37
4CM9FA	100	8.55	4.0	9.0	4.0	9.0	2.14	0.66	2.25	7.57	2.30
4CM20FA	100	6.12	3.2	0.8	3.2	0.8	1.91	1.53	0.25	5.88	2.34
4CM30FA	100	6.31	2.8	1.2	2.8	1.2	2.25	1.58	0.43	6.07	2.33
4CM40FA	100	6.54	2.4	1.6	2.4	1.6	2.73	1.64	0.67	6.29	2.32

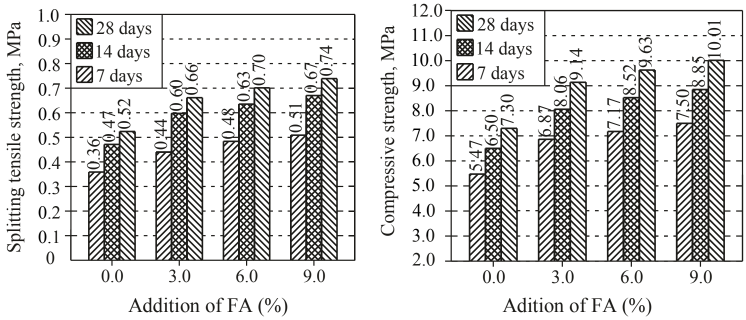
Note: W = Water; B (Binder) = CM + FA;

Experımental methods.
For the strength development, the preparation of the samples was conducted following Table 2. After casting, all samples were covered by a moisture-proof evaporation rag in 20 hours. Subsequently, all samples were demoulded and put into curing container (covered with moisture sacks and sprayed with water to retain moisture) in seven days. Finally, all specimens were immersed in the water at 25^0C until testing days.

For drying shrinkage experiment, the samples were 150 mm in diameter and 300 mm in height. The samples were prepared following Table 2 and each sample was divided into 12 layers. All samples were cured in moisture condition at 25^0C and 100% humidity in seven days. Afterwards, the value of drying shrinkage was measured.

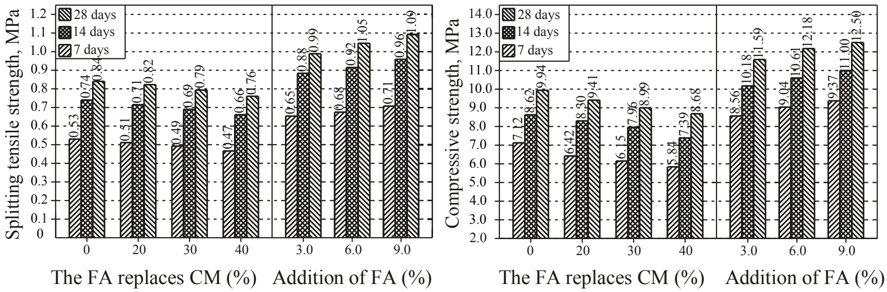
The compressive strength and the splitting tensile strength of CFATB samples were measured according to TCVN 8858 [10] and TCVN 8862 [13], respectively. The measurement of drying shrinkage of CFATB samples was in accordance with ASTM C490 [14] and ASTM C341 [15].

3 Results and discussion



a. Splitting tensile strength b. Compressive strength

Fig. 1. Influence of fly ash on strength characteristics of 3% cement treated ACS mixtures



a. Splitting tensile strength b. Compressive strength

Fig. 2. Influence of fly ash on strength characteristics of 4% cement treated ACS mixtures

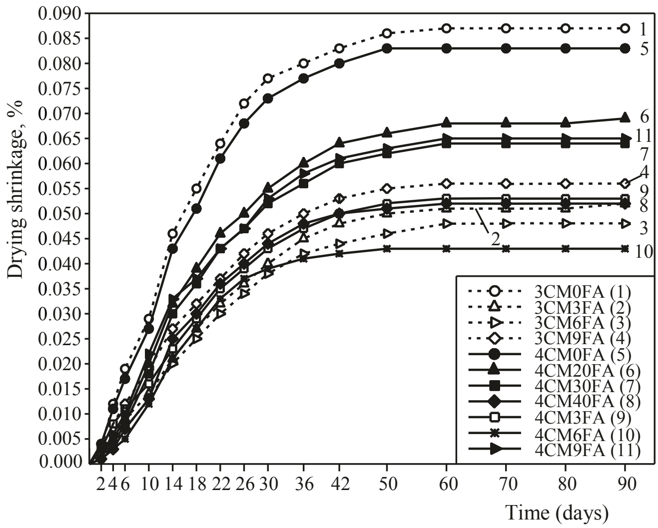


Fig. 3. The drying shrinkage of CFATB mixtures over time

The experimental results of this study are presented from Fig. 1 to Fig. 3. The values of experimental results were the average value deriving from three samples. The following comments can be drawn based on the experimental observations:

- The strength development of CFATB reduces when increasing the FA replacement from 20% to 40%. It can be explained that the high amount of FA leads to the reduction of cement content as well as the increase in the water to cement ratio and water to binder ratio, as seen in Table 2. The slow hydration reaction of FA contributes to the low strength development of CFATB.

- Regarding the different levels of FA addition by weight, the strength developments of CFATB are improved when increasing FA contents. This observation is attributed to the reduction of the water to binder ratio with a constant cement content, as demonstrated in Table 2. Furthermore, the addition of FA contributes to the hydration process and forms more the hydration products such as C-S-H gel and C-A-S-H gel, which improves the strength of CFATB samples.

- As shown in Fig. 3, the drying shrinkage significantly increases in the curing time from 2 to 30 days and slightly increases in the later age days. Especially, the drying shrinkage of CFATB specimens seems not to develop in the curing time from 50 to 90 days. This phenomenon can be explained by the fact that in the early ages, the fast cement hydration reaction leads to a significant development of the drying shrinkage. Additionally, the water evaporation process in these samples contributes to the high drying shrinkage in the early ages. In the later ages (after 30 days), the combination of the completed hydration process and balance of humidity in the samples causes a slight change of drying shrinkage.

- The drying shrinkage reduces when the partial replacement of cement by FA increases from 20% to 40%. This result agrees with Cho Et. al [7].

- The drying shrinkage of CFATB specimens reduces when adding FA from 3% to 6%, while the higher addition of FA (6-9%) causes the increase of drying shrinkage. The addition of FA with a smaller amount (3-6%) fills into the voids of the aggregates and the microstructure of the samples becomes denser. The more FA is added, the higher porosity and the higher humidity these specimens become. The high humidity accelerates the evaporation process of CFATB samples and remarkably increases the drying shrinkage of these mixtures.

4 Conclusions

Some conclusions can be drawn as follows:

1. The strength development of CFATB significantly reduces with the increase of partial FA replacement to cement (20-40%) and remarkably increases with FA addition from 3% to 9%.

2. The drying shrinkage of CFATB significantly increases in the early age of curing. These values slightly increase in the age of 30 to 50 days and seem not to develop in later age from 50 to 90 days. The increase in the FA replacement to cement causes the decrease of drying shrinkage of these mixtures. The addition of FA

decreases the drying shrinkage values. The lowest drying shrinkage values at 90 days of curing were 0.048% and 0.043% of 3CM6FA and 4CM6FA mixtures, respectively.

In this study, the addition of 6% FA in (3 and 4)% cement treated ACS mixtures was the optimal value according to laboratory works with the maximum size of aggregates of 19 mm. However, there are many different conditions between construction site and laboratory works such as over sized aggregates, temperature, humidity, shrinkage surface area, friction coefficient with the underlying foundation, etc and the development of strength over time. Therefore, it is necessary to observe these optimized mixtures (3CM6FA and 4CM6FA) and reference mixtures (3CM0FA and 4CM0FA) on construction sites to give the exact conclusions.

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