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Effect of several fillers on some basic mechanical properties of asphalt concrete

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Abstract: Filler is one of the mandatory ingredients in asphalt mixture. It also plays a very significant role in influencing the properties and behavior of asphalt concrete. This paper presents the results of laboratory experiments to determine the influence of 4 different fillers (including conventional stone powder, Portland cement, rice husk ash, and fly ash) on some mechanical properties of asphalt concrete with D_{max} of 12.5 (AC12.5). The content of filler used in the study was 5% of the total volume of aggregate. The results show that the designed AC with different fillers have the mechanical properties (air void, Marshall stability, flow, and retaining stability) that meet the specification requirements of Vietnam Ministry of Transport Decision No. 858/2014. In which the mechanical properties of AC using conventional stone powder filler are achieved with an overall better and stable effect. Although rice husk ash and fly ash filler also have certain improvements in Marshall stability and air void, AC using rice husk ash and fly ash filler does not meet the requirement of elastic modulus recommended in the Vietnam standard for flexible pavement design 22TCN 211 -06.
Keywords: filler, rice hush ask, fly ash, cement, mechanical properties, asphalt.

1. Introduction

Asphalt concrete (AC) is a mixture of aggregate, filler and bitumen with a certain grade. The filler has importance role to influent on physical and mechanical properties of AC [1]. As mixed with bitumen, they create a mastic mixture with many outstanding features such as increasing bond between bitumen and aggregate, increasing stability, increasing moisture durability and reducing cracks [2–4]. Filler also interacts with bitumen to form a mastic asphalt mixture that plays a very important role in improving some properties of AC [5]. Moreover, the filler particles fill the voids in the AC mixture, leading to increase the density and reduce the voids of AC [6, 7].

Thus, to improve the properties of AC, one of the measurements is to find a way to replace the convention mineral filler (stone powder) by other filler [1], [8]. The use of cement as a partial replacement of mineral powders in the production of asphalt mixes has been reported and that have brought some positive results such as improved rutting and fatigue resistance [9], bond between bitumen and aggregate [10], stiffness [11].

In addition, fly ash, an industrial waste (from thermal power plants) and rice husk, an agricultural by-product, which annually releases huge mass (millions of tons) but have not been properly utilized [12, 13]. Studies show that rice husk ash formed by burning rice husks under suitable conditions has a very large porosity and contains mainly SiO_2 oxide equivalent to the content in silica fume [3, 8, 14, 15]. Fly ash is a mixture of aluminum oxide, calcium oxide, silica oxide, and iron oxide. Both fly ash and rice husk ash is suitable as a mineral admixture for concrete due to high pozzolan activity [16–18]. In the world, there have been a number of studies on applying fly ash and rice husk ash into AC to improve some its mechanical properties such as indirect tensile strength [3, 15], moisture durability [14], Marshall stability [18, 19]. In Vietnam, there have been some initial studies of evaluating some types of fillers such as fly ash, cement on basic properties of asphalt mixture such as Marshall test, direct tensile test, wheel tracking test [9], [17]. The results show that it is possible to replace the traditional mineral powder material with these fillers which can produce AC. Le et al. [8] conducted a investigate using SiO_2 nano made of from rice husk ash as an additive (not filler) to asphalt concrete. It was indicated that rice husk ash additive can increase Marshall stability as well as reduce wheel rutting for asphalt concrete. However, at present, there is no study comparing the possibility of using Portland cement, fly ash and rice husk to replace stone powder in asphalt mixture under Vietnamese conditions.

Therefore, in this paper, the possibility of using cement, fly ash and rice husk ash as filler to replace conventional stone powder was evaluated through some basic mechanical parameters such as elastic modulus, air void, Marshall stability, flow, and retaining stability of asphalt concrete with D_{max} of 12.5 (AC12.5).

2. Materials and mixture design

2.1. Experimental materials

Aggregate (crushed stone D19, D12.5, D4.75) that was taken from Dong-Ao quarry, Thanh-Liem, Hanam satisfied the technical requirements of TCVN 8819:2011 [20] and Decision QĐ-858/2014 [21].

Bitumen 60/70 that was supplied by Petrolimex JSC met the requirements of TCVN 7493:2009 [22] and Circular No. 27/2014/TT-BGTVT [23].

The 4 fillers used in the study include:

(1) Mineral stone powder (SP) was given from Kien-Khe, Hanam met the requirements of TCVN 8819-2011 [20].

(2) Cement Hoang-Thach PCB30 (PC) satisfied the requirements of TCVN 6260:2009 [24] was used.

(3) Rice husk ash (RH) is prepared by burning rice husk, after burning rice husk ash is finely ground by ball mill grinder for 30 minutes.

(4) Fly ash (FA) was be origin from Pha-Lai thermal power plant has been treated by dissociation blowing technology of Vina F&C fly ash factory. The fly ash is equivalent to group F according to ASTM C618-03 [25].

The photos of some fillers in the study are shown in Fig 1.

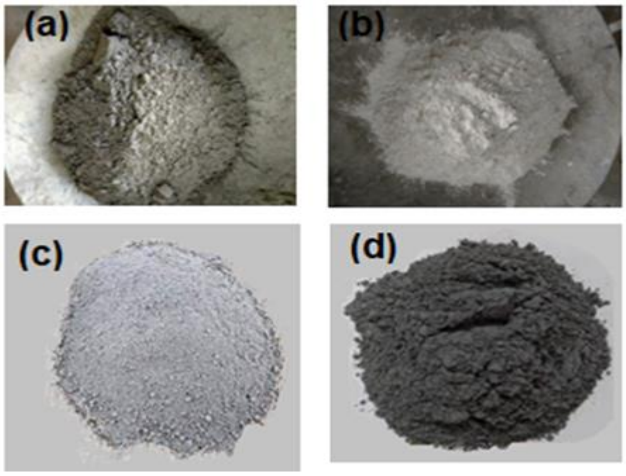

Fig 1. Types of fillers (a) FA, (b) SP, (c) PC, (d) RH

2.2. Mixture design

Mixture AC12.5 is designed according to Marshall method and satisfying Decision 858/QĐ-BGTVT [21].

The aggregate mixture includes 18% D19, 37% D12.5, 40% D4.75 and 5% filler. Aggregate grading distribution of AC12.5 after mixing is shown in Fig 2.

AC12.5 mixture consisting of aggregate, filler, bitumen 60/70 was mixed according to the designed ratio with the aggregate grade as described above and the bitumen content accounted for 4.9% by weight of dry aggregate.

Fabrication of AC12.5 samples with variable fillers including SP, PC, RH, and FA to conduct experiments. The process of mixing AC samples using different fillers is similar to AC using mineral fillers. The experimental plan is shown in Table 1. The Marshall specimens is illustrated in Fig 3.

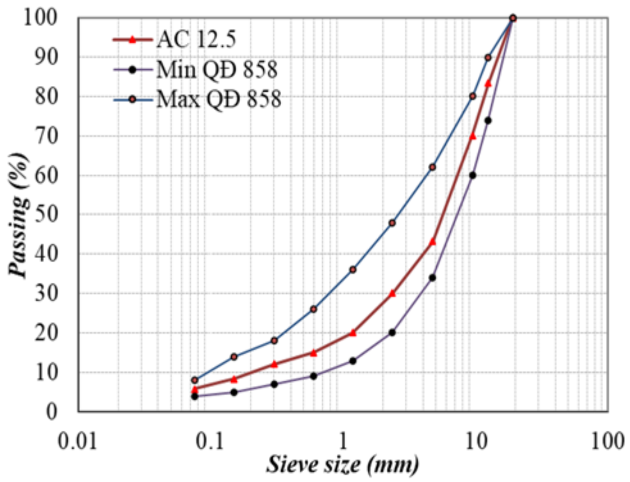

Fig 2. Aggregate grading of AC12.5

Table 1. The experimental plan

	Experiment	Number of specimens (sps)
1	Marshall Stability, flow and retaining stability	3 sps * 2 cases * 4 fillers = 24 sps
2	Air void	3 sps* 4 fillers = 12 sps
3	Elastic modulus	3 spes * 4 fillers = 12 sps

Fig 3. Marshall specimens

2.3. Experimental program

(1) Marshall Stability, flow and retaining stability test

Marshall stability and flow are performed according to the standard TCVN 8860-1:2011 [26]. Cylindrical AC sample of specified size (101.6 mm diameter and 63.5 mm height) was immersed in a water bath with thermostat at 60^{o}C during 40 mins or 24 h. Then the cured samples are tested under the Marshall machine (Fig 4) with constant displacement. The maximum compressive force value is the Marshall stability while the recorded strain at the same time is the Marshall flow. Marshall stability and flow are very important criteria for design, construction and acceptance of AC pavement.

Fig 4. Marshall machine

Retaining stability of asphalt concrete (R, %), is one of the criteria for the design and quality control of AC, is used to evaluate the influence of water on AC. Retaining stability was determined according to TCVN 8860-12:2011 [26]. Retaining stability of asphalt concrete can be calculated by the follow formula:

$$R=\frac{S_a}{S}\times 100\% \qquad (1)$$

Where: S is the Marshall stability of AC sample immersed in a water bath at 60°C for 40 min; Sa is the Marshall stability of AC sample immersed in a water bath at 60°C for 24 h.

(2) Air void test

Air void (V_a, %) is the total volume of air voids between aggregate particles coated by bitumen in the compacted AC mixture. The air void was determined based on the maximum density of loosed AC and the bulk density of compacted AC (Fig 5). Air void test was carried out according to TCVN 8860-9:2011 [26]. The air void of the AC mixture is one of the criteria used in the design of the mix and the assessment of the level of compaction at the site.

Fig 5. Air void test

(3) Elastic modulus test

The elastic modulus of the flexible pavement structure is the deformation resistance property of the pavement structure that includes the surface and the effective area under the effect of standard wheel loads. The elastic modulus of pavement structure is one of important criterion of design criteria of pavement structure. The elastic modulus (E, MPa) is determined according to Appendix C.3.1 of 22 TCN 211-06 [27]. The test sample is a cylindrical size 100x100 mm, immersed in a thermostatic water tank at the test temperature (30°C) for at least 2.5 h. The displacement rate of 0.01 mm/min was kept constant during the test. The elastic modulus is determined by the following formula:

$$E=\frac{4P.H}{\pi.D^2} \quad (2)$$

Where: D is diameter of specimen (mm); H is sample height (mm); P is load (kN).

3. Results and discussion

3.1. Marshall Stability

Fig 6 shows the results of Marshall stability tests for AC sample using different filler types immersed in 60 °C water at 40 min and 24 h. The results show that all AC samples satisfy the Marshall stability requirements of 858/QD-BGTVT [21] (greater than 8 kN). In which, the Marshall stability value of AC using RH (13.32 and 12.94 kN) is the highest while that of FA is the lowest (9.35 and 8.63 kN). Using RH filler can improve Marshall stability about 3.5% (in case of 60°C/40min) and 3.1% (in case of 60°C/24h). However, using PC and FA filler reduces Marshall stability compared to conventional SP filler about 2.6 and 5.2 % (in case of 60°C/40min) and 2.7 and 5.7% (in case of 60°C/24h), respectively.

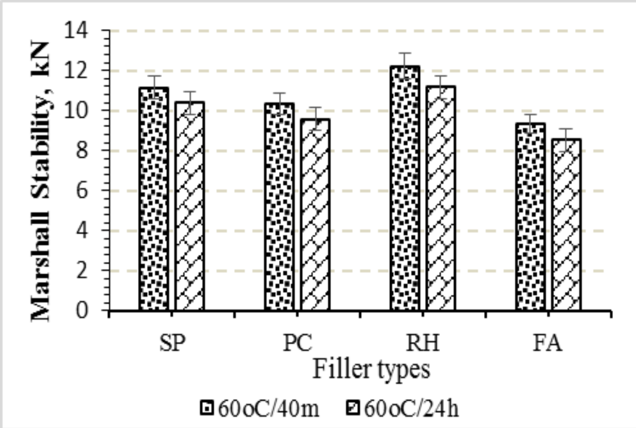

Fig 6. Marshall stability result

3.2. Marshall Retaining stability

The results showing the Marshall Retaining stability of the samples are shown in Fig 7.

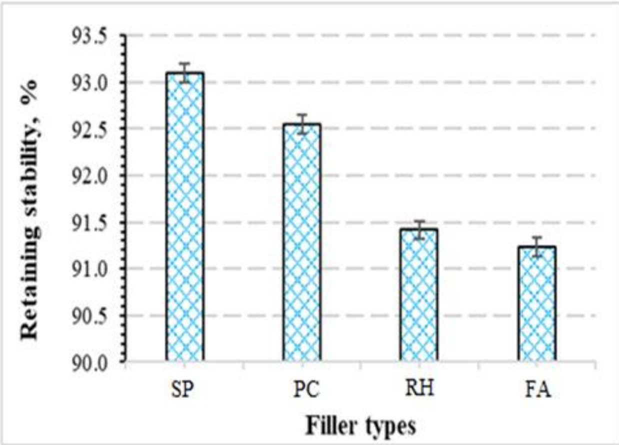

Fig 7. Result of Marshall Retaining stability

The results show that the Retaining stability of the AC sample using SP is the highest (93.1%), and the Retaining stability of the both AC samples using RH and FA filler is approximately the same and the lowest (91.4% and 91.2%, respectively). All samples have the Retaining stability of meeting the technical requirements according to 858/QD-BGTVT [21] (greater than 80%) and according to TCVN 8819-2011 [20] (greater than 75%).

It can be seen that the replacement of conventional fillers also decreases the Retaining stability of AC, although this reduction was not significant. Specifically, compared with AC using conventional SP, AC using PC, RH and FA filler has reduced stability by 0.53%, 2.1% and 2.2% respectively.

3.3. Marshall flow

The results of the Marshall flow test for the AC sample using different filler types are shown in Fig 8. The flow values of all AC satisfied the standard 858/QD-BGTVT [21] (1.5-4mm). The flow value of AC using RH filler is the highest (3.88 mm), while PC filler bring the lowest flow value (2.67 mm).

It can be seen that when using RH filler, it helps to increase flow (about 19.8%) compared to using conventional SP filler. In contrast, using PC and FA reduced flow (about 17.6% and 6.17% respectively). This shows that the rice husk ash filler has more dispersing effect.

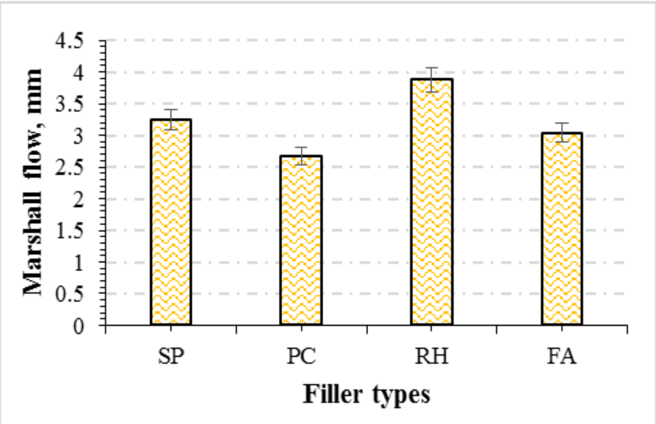

Fig 8. Result of Marshall flow

3.4. Air void

Fig 9 shows the air void of AC samples using different filler types. The results show that all the AC samples satisfy the technical requirements of TCVN 8819:2011 [20] (3-6%) and 858/QD-BGTVT [21] (4 - 6%). However, the air void of the samples using RH filler was the highest (5.52%) and the FA filler was the lowest (4.96%).

Compared with SP filler, both PC and RH filler have higher air void which is 4.5% and 9.74% higher, respectively. In contrast, AC using FA filler reduced the air void by 1.4% compared with that of SP filler.

Thus, using FA filler replacing SP filler can get a little reduction the air void of AC that makes AC mixture denser. On the contrary, using PC or RH filler increase the air void.

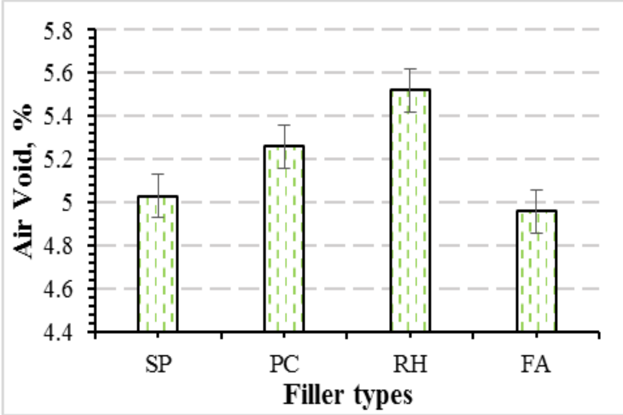

Fig 9. Result of air void

3.5. Elastic modulus

The results of elastic modulus at 30°C of AC using different filler types are shown in Fig 10. The results show that AC using SP filler has the highest elastic modulus (436 MPa) and the AC using FA filler has the lowest (406 MPa). It can be seen that using PC, RH and FA filler reduces elastic modulus as compared with SP filler about 3.5%, 8.14% and 6.4%, respectively. According to the specification in 22TCN 211-06 [27], the elastic modulus at 30°C of AC (with crushed stone content greater than 50%) must be higher than 420 MPa. Thus, AC using SP and PC meet the requirements, while RH and FA do not meet this requirement.

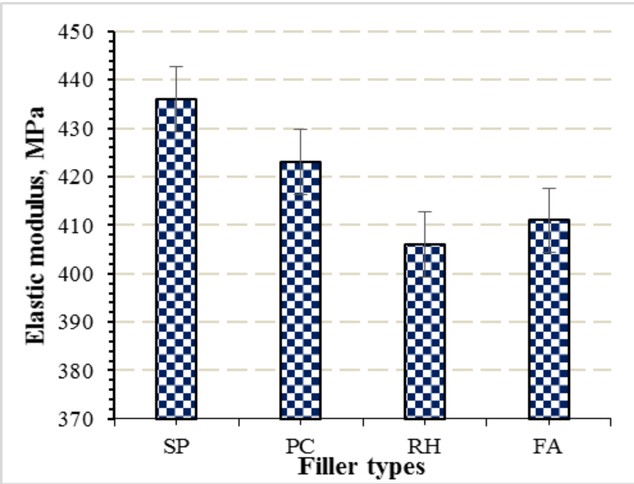

Fig 10. Result of elastic modulus

The mechanical properties of AC samples in the study are summarized in Table 2.

It can be seen that when using different fillers in AC12.5 with 5% content of AC mixture mass, basically these types of concrete meet the criteria in Decision 858-2014 [21]. As using PC filler does not achieve the effect of improving properties compared to SP filler. Although using RH improve Marshall stability, it reduces Retaining Stability and increases air void quite a bit. In contrast, FA filler had a good improvement in air void but decrease stability and retaining stability. This can be explained by the fact that RH and FA both have much smaller particle sizes than SP and PC. RH has a large proportion of particles that are smaller than the thickness of the bitumen film, so it creates a stable mastic mixture and high stability. On the contrary, FA has a large proportion of particles that are larger than the thickness of the bitumen film, so it has the effect of filling the voids, increasing density and reducing the air void. It is noticed that RH and FA filler fail to meet the elastic modulus requirement in 22TCN 211-06 [27].

These results nearly similar to the studies of in cases replacing SP filler by FA and PC [4, 8, 9, 17, 28]. It can be seen that normal SP filler still shows a stable and better effect than the other fillers in AC12.5 mixture. However, some studies suggested that as SP replaced partially by PC, FA or RH with a reasonable ratio will bring better mechanical properties such as Marshall properties, elastic modulus, direct tensile strength, rutting resistance [4, 5, 9, 17, 19, 27].

Therefore, in further studies, the evaluation of the optimal ratio of partial replacement of SP with PC, FA or RH will continue to be carried out.

Table 2. The summarized mechanical properties

	Stability (MPa)		Flow (mm)	Retaining Stability (%)	Air void (%)	Elastic modulus (MPa)
	60°C/40min	60°C/24h				
SD	11.16	10.39	3.24	93.1	5.03	442
PC	10.34	9.57	2.67	92.6	5.26	431
RH	12.23	11.18	3.88	91.4	5.52	406
FA	9.35	8.53	3.04	91.2	4.96	411
Required	>8 [21]	>6.4 [21]	1.5-4 [21]	>80 [21]	4-6 [21]	>420 [27]

4. Conclusions and recommendations

Experimental study using different fillers (PC, RH, FA) to completely replace SP filler in AC12.5 with the same content of 5% of the total weight showed that the designed AC mixture have the mechanical properties (Marshall properties and air void) meet the technical criteria compared to the requirements of the Vietnam current standard. However, the mechanical properties of AC using PC filler are all lower than those of conventional SP filler. Using RH and FA filler also yielded certain improvements in Marshall stability and air void. However, RH and FA filler are not met the 22TCN 211-06 requirements of elastic modulus. There is potential for the use of different filler materials in AC mixtures. In the future work, the further studies to determine the optimum filler ratio when partial replacement of SP filler with PC, RH and FA will be carried out for improving a better properties of AC.

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