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THE ROLE OF ADDITION OF CALCIUM ALGINATE MICROCAPSULES ON PERMANENT DEFORMATION OF AC–WC NATURAL ASPHALT BUTON STONE IN INDONESIA

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This paper discusses natural asphalt deposits of Buton stone (asbuton) in Indonesia are very abundant, but the characteristics of asbuton are not yet suitable for road applications. So that the use of asbuton as a binder needs to be added with additives that can react independently to overcome the permanent deformation such as the addition of calcium alginate microcapsules to the asphalt mixture. The purpose of this study was to determine the effect of adding calcium alginate microcapsules to the permanent deformation of AC-WC with asbuton.

The current problem is that road pavements are not able to heal themselves when cracks start to occur, so additional materials are needed that can stimulate self-healing to occur so that the cracks that have started to occur can be closed again even though it takes time so that the self-healing process can occur.

The microcapsules are made with the main ingredients of water, sunflower oil, sodium alginate ($C_6H_7O_6Na$) and calcium chloride solvent ($CaCl_2$), which are encapsulated and embedded in the asphalt mixture as a material that can restore the structural function by a healing method self healing. The research method uses true experimentally. Specimen variations in the study were the addition of calcium alginate microcapsules of 0 %, 1 %, 1.5 %, 2 %. Wheel Tracking Testing was carried out with the AASHTO Standard: T 32-11 and CAL Testing with the Tex-245-F 2014 standard. The results showed that with the addition of calcium alginate microcapsules, there was no significant contribution; better than microcapsules, the mixture decreases in the number of passes so that the mixture is easy to change shape rutting. However, adding calcium alginate microcapsules can reduce the value of weight loss, causing the adhesion of the asphalt mixture to increase

Keywords: buton asphalt, calcium alginate, microcapsule, permanent deformation, cantabro abration loss

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1. Introduction

Permanent deformation is damage to the asphalt mixture in the pavement structure. The factors that cause this damage are traffic loads, mixed design, environmental factors, and so on [1]. Asphalt, which has an important role in determining the durability of pavement performance, has a service life according to traffic needs and conditions. However, asphalt pavements often experience aging [2], causing damage to the pavement. The damage usually starts with micro-cracks and progresses to more complex damage such as permanent deformation [3]. Because the crack problem disappears, it can trigger new problems, namely permanent deformation [1]. A researcher stated that the addition of alginate to the mastic asphalt mixture could heal micro-cracks so that it could maintain a low pavement life [4].

Using natural asphalt in Indonesia is asbuton, which can be used as an additive or binder on road pavements and as a substitute for oil asphalt [5]. However, asbuton has poor characteristics because the bitumen and mineral content in asbuton has not met the asphalt specifications used in Indonesia. In addition, many pavements using asphalt have not reached the design life because of cracks. So that if asbuton is used as a binder in asphalt mixtures, it can cause premature failure of the pavement and cause permanent deformation [6].

Therefore, research on adding additives to the self-healing process in pavement mixtures containing asbuton is relevant to be carried out.

2. Literature review and problem statement

Several researchers have conducted research related to the characteristics of asphalt using added materials. Preventing a decrease in the quality of the pavement mixture is done by modifying the asphalt mixture with the addition of materials that can react independently to structural changes [7]. These materials can restore the function of the pavement structure, which is called self-healing. Suggested self-healing materials for further research should be resistant to mixing and compaction temperatures, used for long-term service, active at ambient temperatures, where the asphalt pavement temperature is 20–60 °C and self-healing such as calcium alginate [8]. Survival rate of microcapsules can be increased by reducing the microcapsule size and mixing temperature to ensure that the microcapsules can survive the construction process and be activated by cracks [9]. It indicates that the rejuvenating encapsulated asphalt can be released at the time of cracking in the asphalt mixture [10].

Pavement self-healing ability is considered a useful method for pavement maintenance management [11]. By adding self-healing materials can increase the service life of asphalt pavement [12]. Self-healing capsules mixed into asphalt mixtures can improve healing over time [13]. Apart from using capsules, self-healing can also be done by means of modified carbon fiber reinforcement [14].

However, in previous studies, no analysis has been carried out on the contribution of calcium alginate microcapsules to the adhesion resistance of asphalt mixtures, and no one has discussed the addition of calcium alginate microcapsules to asbuton related to permanent deformation.

Therefore, this study suggested that the percentage of microcapsules added to the asphalt mixture should be limited. Because more and more addition of calcium alginate microcapsules can cause the mixture to be filled with cavities so that the mixture is dense and decreases in the level of the resilient modulus or the level of elasticity. The low elasticity of the mixture causes the mixture to be brittle and prone to deformation such as rutting. Therefore, this study as an effort to optimize the use of asbuton. Based on previous research on self-healing of Buton asphalt mixtures [15]. So the researchers intend to add calcium alginate microcapsules to determine their role on the permanent deformation of AC-WC asbuton.

3. The aim and objectives of the study

The aim of this study is identifying mechanical performance of the mixture on the Aspal Buton when calcium alginate capsules were introduced. This will make it possible to decrease caused by wheel load and the increase in driving capacity.

To achieve this aim, the following objectives are accomplished:

– to perform wheel tracking test on a test object according to the AASTHO T 324-11 standard, so that it can be seen how permanent deformation occurs;

– to test for Cantabro Abration Loss (CAL) on the test object using a Los Angeles testing machine, so that the percentage of particle loss can be known, then linked to the Marshall test results.

4. Materials and methods

4. 1. Object and hypothesis of the study

The mechanical performance of the asbuton hardening mixture applied to the calcium alginate microcapsule is described in this work. assuming that depending on the quantity and kind of microcapsules, the administration of these additives alters mechanical performance. Therefore, the impacts of mechanical performance may be described by the action of these microcapsules. Whether these additives can improve mechanical performance or make it worse, they can nevertheless enhance bonds during the hardening process.

4. 2. Materials

Materials in this study include:

a) the oil asphalt used is Ex asphalt. Pertamina Pen 60/70;

b) the asphalt used is Asbuton Type B 50/30 with a pure asphalt content of about 24.75 %, which is processed to become Lawele Granular Asphalt (LGA). The asphalt used in this research is Asbuton B 50/30 and Asphalt Pen 60/70 with the research results as shown in Table 1;

c) the use of additive materials in this research is calcium alginate microcapsules with the main ingredients in the form of water, sunflower oil which contains fat. Saturated sodium alginate ($C_6H_7O_6Na$) and calcium chloride solvent ($CaCl_2$) Composition of the Microcapsule Mixture, as shown in Table 2. Aggregate is the main component of the road pavement structure, which is 90–95 % aggregate based on weight percentage, or 75–85 % aggreagate based on volume percentage. The aggregates used are 10/15 sized aggregates; 5/10, 0/5, and stone ash which was sifted according to the AC – WC gradation.

Fig. 1 is the size limit of the material between coarse aggregate and fine aggregate, which will be used uniformly for all samples.

Table 1

Characteristics of asphalt and asphalt pen 60/70

Properties	units	Value
Asbuton		
Asbuton Bitumen Content	%	25.42
Penetration at 25 °C	(0.1 mm)	45.20
Softening Point	°C	50.5
Ductility at 25 °C	cm	116
Specific gravity	gr/cc	1.063
Asphalt Pen 60/70		
Penetration at 25 °C	%	54.3
Softening Point,	(0.1 mm)	334
Ductility at 25 °C,	°C	150
Flash Point,	cm	320
Specific gravity	gr/cc	1.041

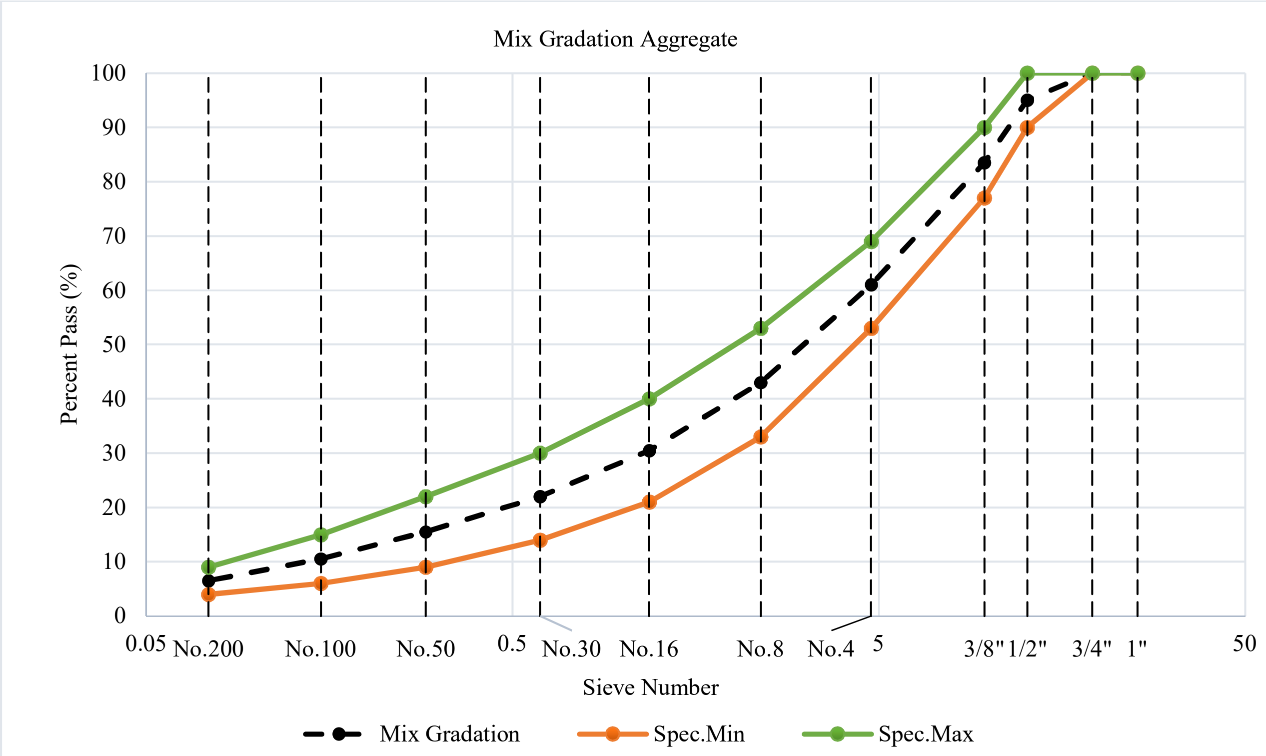


Fig. 1. Combined Aggregate Gradation

Table 2

Table composition of the microcapsule mix

Capsule Type	Sodium Alginate Emulsion			Oil water ratio
	Sodium Alginate (g)	Sunflower Oil (ml)	Water (ml)	
CA1	15	100	500	1:5
CA2	15	150	450	1:3
CA3	15	200	400	1:2

Table 3

Specifications of coarse and fine aggregates

Properties	Value
Fineness Modulus of Coarse Aggregate	5.04
Bulk Specific Gravity, gr/cm^3	2,621
Apparent Density, gr/cm^3	2,726
Water absorption, %	1,480
Los Angeles Abrasion, %	15.23
Impact, %	14.4
Flatness Index, %	23.5
Elongation Index, %	17.3
Fine Aggregate Fineness Modulus	3.06
Bulk Specific Gravity, gr/cm^3	2,607
Apparent Density, gr/cm^3	2,797
Water absorption, %	2,606

Fig. 1 shows the gradation of the upper and lower limits. In this study, the middle boundary gradation is used so that the determination of the gradation does not come out of the gradation specification

4. 3. Experiment setup

In Ministry of Public Works and Public Housing specification the percentage of use of asbuton item B 50/30 is limited from 7–10 % [1], so that in this study, asbuton used was 8 %, namely 2 % bitumen content and 6 % mineral content.

In accordance with the specifications, Fig. 2 explains the stages and process of making the test object to the form of the test.

The design asphalt content used is 5 %; 5,5 %; 6 %; 6.5 % and 7 %. From the Marshall test characteristics test results where the relationship between stability, flow, VIM, VMA and VFB, the optimum asphalt content value (KAO) is 6.1 %. load of 705±4.5 N (158±1.0 lb). The temperature used is 50±1 °C. The Humburg Wheel Tracking (HWT) can test two pairs of test objects simultaneously. The steel wheel diameter is 203 deformation. The variation of the addition of microcapsules in this study was 1 %; 1,5 %; 2 % of the total weight of the mixture. The analysis results were obtained from the average repetition value of 3 test objects namely:

1. Wheel Tracking test refers to AASHTO standard: T 324–11. This research uses a wet (soaked) wheel tracking test with the test object immersed in water for 30 minutes.

The test apparatus was operated using steel wheels with a mm (8 in) and 47 mm (1.85 in) wide and the test apparatus oscillates at 52±2 passes per minute.

2. Cantabro Abrasion Loss Testing (CAL) using the standard Tex – 245 – F, 2014. The cantabro value is determined from the weight loss of a mixture after being tested with a Los Angeles engine of 300 revolutions. The weight loss in the mixture was calculated at each 50, 100, 150, 200, 250 and 300 rotational intervals at a speed of 30–33 rpm at room temperature, without steel balls. The data from the test were in the form of microcapsule shell rupture and oil flow time in the cracks.

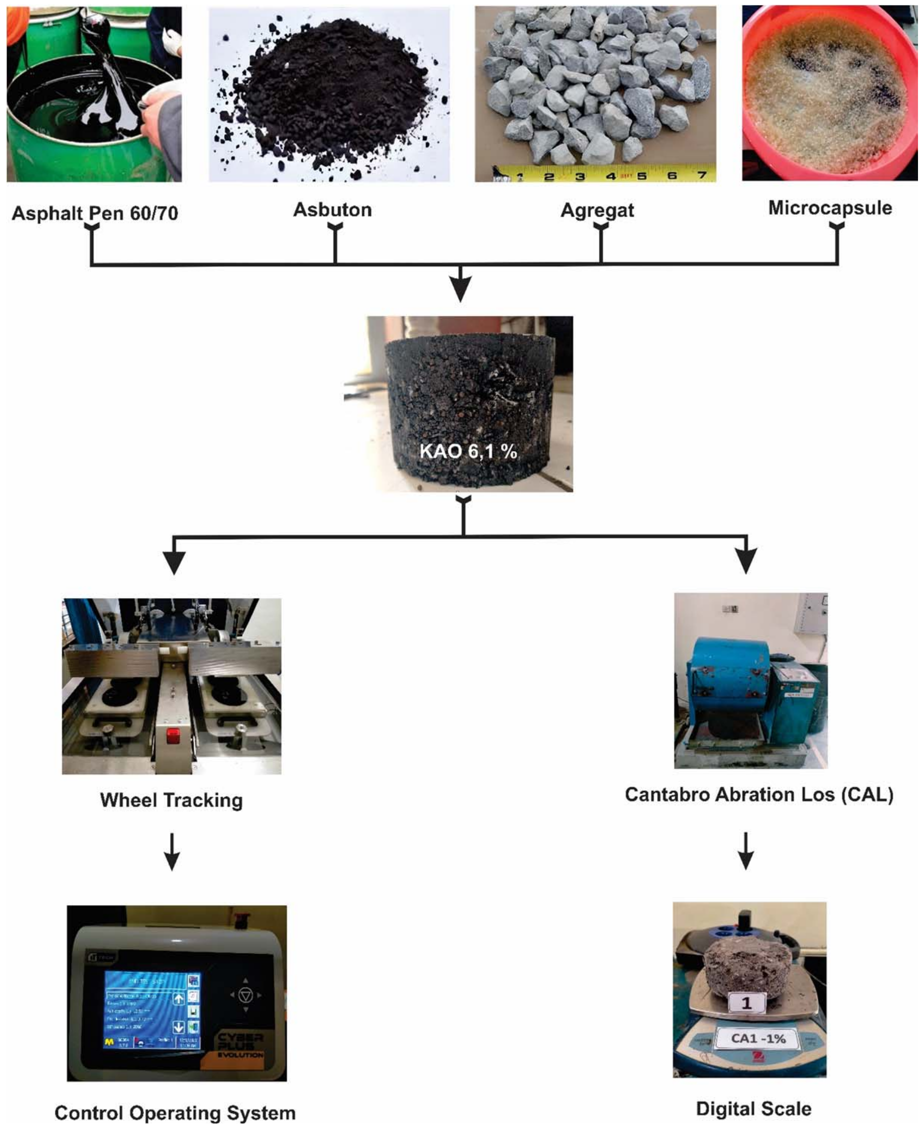


Fig. 2. Experiment testing set up

5. Results of permanent deformation study of pavement mixture with microcapsule calcium alginate additive

5. 1. The relationship between Marshall test results and wheel tracking

Marshall value analysis is indicated by the stability value whose magnitude is measured directly from the test when the test object is loaded with Marshall test equipment. The stability value of the asphalt mixture with the addition of calcium alginate microcapsules is shown in Fig. 3.

Fig. 2, 3 show that the asphalt mixture with the addition of calcium alginate microcapsules has the same pattern of stability values and the value of resistance to rutting, which is decreasing. Due to the decrease in the stability value and the number of passes on the asphalt pavement, it can be seen that there is no good contribution with the addition of calcium alginate microcapsules to the asphalt mixture so that the mixture is easy to change shape such as waves, grooves (rutting).

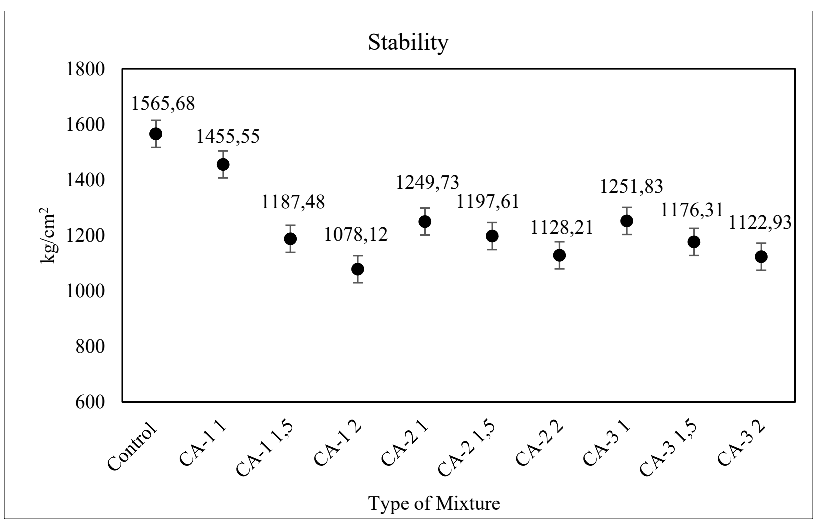


Fig. 3. Marshall stability test results

Whell Tracking Testing on 10 variations of the pavement test object containing calcium alginate capsules, can be in Fig. 4, the figure shows the decrease and the number of passes for each test object.

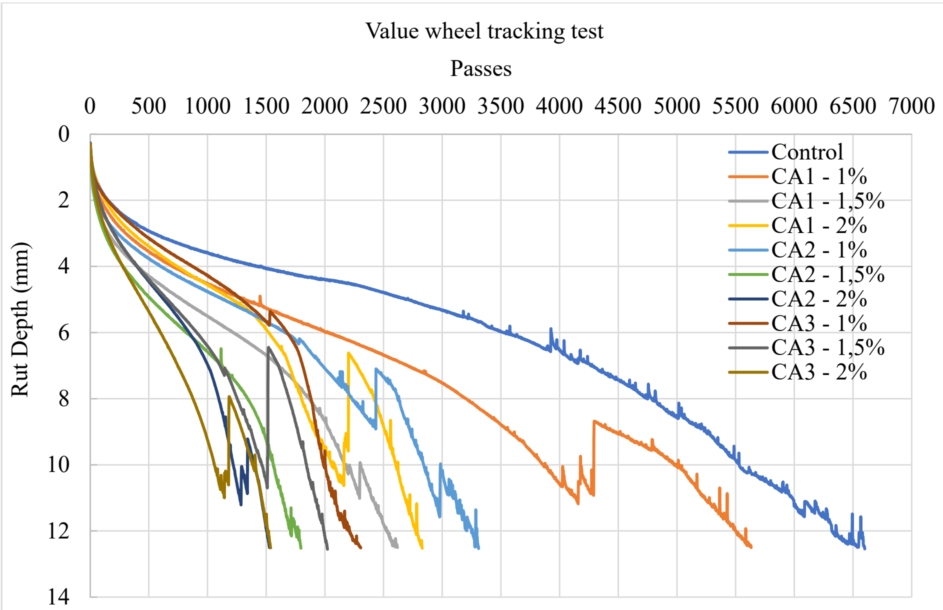


Fig. 4. Wheel Tracking Test Result

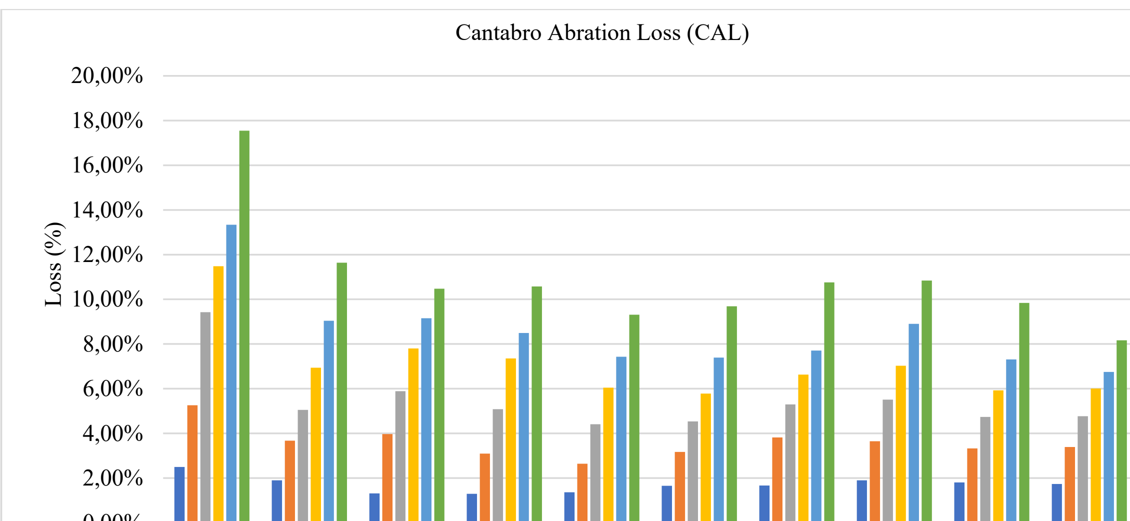
Wheel Tracking test with the relationship between track values and rutting depth. The Wisconsin specification of critical rutting depth for identifying wheel tracking tests is 12.5 mm on a 10,000 cycle track [2]. Therefore, this test was carried out to distinguish the number of passes for each variation of the test object after reaching a rutting depth of 12.5 mm (Fig. 4).

Fig. 4. shows that with a large percentage of additive administration it will affect the number of passes in the sample, there is a decrease in sample performance, but in samples that do not contain added ingredients it looks more stable the number of passes received with the decrease that occurs, this is actually a challenge for the next stage so that the percentage of the additive does not adversely affect the sample of the test object.

5. 2. Cantabro Abrasion Loss Result (CAL)

The following Fig. 5 is an illustration of the loss of particles in the samples tested using.

The results of the CAL test are as shown in Fig. 5, namely the graph of the test results for the weight loss of the asphalt mixture. Fig. 5 shows the role of calcium alginate microcapsules on the test object. The adhesion of the specimens was better with the addition of microcapsules than the specimens without the addition of microcapsules, where the test object without the addition of microcapsules has a weight loss value that does not meet the specifications.



	Control	CA1-1%	CA1-1,5%	CA1-2%	CA2-1%	CA2-1,5%	CA2-2%	CA3-1%	CA3-1,5%	CA3-2%
50 Round	2,50%	1,90%	1,32%	1,30%	1,37%	1,65%	1,67%	1,90%	1,81%	1,74%
100 Round	5,26%	3,67%	3,97%	3,10%	2,64%	3,17%	3,82%	3,65%	3,33%	3,39%
150 Round	9,43%	5,05%	5,89%	5,08%	4,41%	4,54%	5,30%	5,51%	4,74%	4,77%
200 Round	11,48%	6,94%	7,80%	7,36%	6,04%	5,79%	6,63%	7,03%	5,93%	6,01%
250 Round	13,34%	9,04%	9,15%	8,49%	7,43%	7,39%	7,71%	8,90%	7,31%	6,75%
300 Round	17,55%	11,64%	10,48%	10,57%	9,31%	9,69%	10,76%	10,84%	9,84%	8,17%

Fig. 5. Graph of Cantabro Abrasion Loss (CAL) test results

Fig. 6 is a visual of the samples that have been tested using the Los Angeles Machine, this test without using steel balls. It is possible to see the difference in the same test object before reaching 250 rounds and after 300 rounds.

a

b

Fig. 6. Self-healing achievements: *a* – the condition of the test object before the 250–300 round; *b* – the condition of the test object at 250–300 rounds

Fig. 7 is a visual of the test object that has been tested and left for a few moments, it can be seen that the additive content of the microcapsule begins to spread to all parts of the sample.

Fig. 7. A rest period of the test object

With the release of oil from the microcapsule, it shows that this additive works after experiencing grinding up to 300 times, at the beginning between 1–250 rounds, the sample does not appear to have released the additive content, but after 250–300 rounds it is possible that the sample has been saturated so that cracks occur in the sample causing it to remain cause this additive to work.

6. Discussion of permanent deformation study of pavement mixture with microcapsule calcium alginate additive.

This paper presents the results of research on permanent deformation that occurs in asbuton asphalt pavement mixtures when given calcium alginate microcapsule. The research is expected to be able to solve problems that are currently occurring related to the service life of Buton asphalt pavements. So that the problem of service life from the use of buton asphalt can be resolved. The approach taken is by conducting a mechanical test to find out the degree of permanent deformation that occurs. However, it is advisable to conduct research on permanent deformation of buton asphalt mixtures, which have additives for self-healing.

This study used the wheel tracking and Cantabro tests, so that the characteristics of the permanent deformation that occurred could be seen. Based on Fig. 4, the value of the number of passes decreased with the addition of calcium alginate microcapsules to the test object without the addition of microcapsules. The addition of CA1 microcapsules decreased by 49,91 % for the test object. The test object with the addition of CA2 microcapsules decreased by 68.36 %. And for the test object with the addition of CA3 type microcapsules decreased by 72.76 %. From the results of the analysis, it is known that the type of microcapsules affects the resistance of the specimens to rutting. This is because the composition of the oil-water in the microcapsules affects the size of the microcapsules, where the more addition of sunflower oil can produce a larger microcapsule size. Thus causing a lack of contribution of calcium alginate microcapsules to the mixture's resistance and causes the mixture to tend to have the potential to undergo permanent deformation at the time of loading.

The lack of resistance of the test object to rutting was also caused by the increasing number of additions of microcapsules. Variations in the addition of microcapsules in this test are 1 %, 1.5 % and 2 %. The test results found that each additional variation experienced a decrease in the number of passes with a rutting depth of 12.5 mm. The type of CA1 microcapsules decreased by 48.92 %, CA2 microcapsules decreased by 52.38 %, and CA3 microcapsules decreased by 42.63 %. The rutting depth increased when the number of capsules in the asphalt mixture increased. However, the increase in rutting is proportional to the release of oil [16-18].

Based on Fig. 5, it is known that the addition of microcapsules can reduce the value of weight loss in the asphalt mixture. At a rotation of 300 test objects as control (without the addition of microcapsules) decreased weight loss by 6.97 % of the test objects with the addition of microcapsules of the type CA1; 6.79 % of the specimens with the addition of CA2 type microcapsules; 9.39 % of the test object with the addition of microcapsules of the type CA3. This shows that the addition of calcium alginate microcapsules can increase the value of adhesion to the asphalt mixture, which states that the asphalt mixture with the addition of capsules has a lower particle loss than without capsules [18, 19].

The weight loss value decreased by 1.06 %; the type of CA3 microcapsules as much as 2.67 %. However, for the type of CA2 microcapsules, the weight loss value increased by 1.45 %. Based on the opinion, all asphalt mixtures with the addition of microcapsules met the required specifications, namely weight loss of 15 % [5].

Fig. 5 shows that the capsule will not crumble and will not undergo rejuvenation. Calcium alginate microcapsules used as self-healing additives in hot asphalt mixtures with asbuton will break when subjected to repeated loads. Calcium alginate microcapsules rupture at 250–300 revolutions. Which before the time of cracking occurs, calcium alginate microcapsules are active when the asphalt mixture experiences fatigue due to load [20]. Microcapsules must be active during the service period in the field and inactive during the process of mixing and compacting the asphalt mixture. The results showed that calcium alginate microcapsules had sufficient thermal and mechanical resistance to withstand mixing and asphalt compaction [8]. The limitation of this research is that it is only done in the laboratory, and the analysis of self-healing achievement is only done visually, not counting the speed of self-healing flow. Therefore, it is suggested that future researchers analyze the role of calcium alginate microcapsules on crack healing in asphalt mixtures.

Fig. 6 shows that when the calcium alginate microcapsules rupture, the microcapsules deform, or the shells rupture under the load and release the liquid or oil in them to spread and flow through cracks in the pavement in less than 24 hours. The healing index is directly related to the amount of oil secreted by the capsule. The fatigue resistance of asphalt mixtures is reduced when larger capsules are used. This capsule type enhances the healing properties due to the higher amount of sunflower oil secreted by the capsule. The capsules can delay cracking and increase asphalt durability by up to 21 % [21].

The achievement of self-healing of hot asphalt mixture with asbuton in this test was obtained from the correlation results of the CAL test. From the CAL test, the condition of the specimen is known after the rupture of the calcium alginate microcapsules, as shown in Fig. 5.

Further development requires a stronger capsule shell so that the permanent deformation that occurs can be maximized.

Fig. 7 shows that the microcapsule shell ruptured, and during the resting period, the self-healing fluid flowed between the cracks. The liquid flow will rejuvenate the asphalt and regenerate the old asphalt binder due to the load to restore the integrity of the material and prevent structural damage to the pavement.

The limitation of this study is the permanent deformation that occurs reduces the ability of the pavement mixture so that there is a need to increase the quality of the calcium alginate microcapsule. It is estimated that the permanent deformation is caused by the weak strength of the shell on the microcapsule, so that a lot of air voids form in the pavement mixture. With the addition of additives, it is expected to extend the life of this pavement, because the effect of this additive is expected to be able to stimulate self-healing because it contains vegetable oil, which can re-glue the pavement mixture that is starting to experience cracks. However, this pavement mixture can still be used for pavements that have light traffic, and further research is needed to determine the time needed to start the self-healing process.

7. Conclusions

1. Mechanical testing using the Whell Tracking method found that there was a decrease in performance when viewed from the decrease due to wheel load, all the samples tested showed similarities to the Marshall test results so it was concluded that calcium alginate microcapsule material when mixed into asbuton pavement still causes performance to decrease. The decrease occurred constantly according to the type of capsule starting from CA1, CA2, and CA3 respectively 49.91 %, 68.36 %, 72.76 %.

2. The positive side of the addition of the calcium alginate microcapsule is that particle loss can be reduced by up to 8 % of the total weight when compared to a mixture without this additive, because the particle loss is 17 % if done on the Los Angeles apparatus with 300 rotations.

Conflict of interest

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

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Data availability

Manuscript has no associated data.

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