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Experimental Evaluation of Anti-Stripping Additives Mixing in Road Surface Pavement Materials

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Abstract: Most road surfaces in Taiwan are paved with asphalt concrete but the phenomena of rutting, cracking and stripping of the pavement are frequently occurring due to the effects of traffic flow, thermal variation and water erosion caused by rain. In this study, a series of experiments were performed to examine the effectiveness of anti-stripping fillers, which include; rock flour, rock flour with 1% lime and rock flour with 1% cement, respectively, in the mixture of asphalt concrete. The experimental mixing results showed that the case of rock flour with 1% lime has a relatively better performance in several categories including stability value, flow value, retained strength, wrapped asphalt rate in grains, resilient modulus, dynamic stability and rate of rutting deformation. The evaluated information implies that this filler can increase the asphalt concrete's abilities to resist rutting deformation and stripping of the road surface, thus increasing the durability. The results also provide a good reference for using in road construction with similar regional characteristics to Taiwan.

Key words: Road engineering, anti-stripping additives, rock flour, lime, cement

INTRODUCTION

Most roads around the modern world are paved with asphalt concrete due to its advantageous properties such as a sound mechanical composition, ease of repair and provide ease of use for users. Basically, the asphalt concrete is composed of asphalt mortar, coarse aggregate, fine aggregate, mineral filler and air. This flexible material has to be mixed by a constant proportion of each ingredient under a controlled temperature condition to guarantee the quality of a road surface[1,2]. However, this temperature sensitive pavement material suffers from rutting, cracking and stripping caused by the effects of traffic flow, thermal variation and water erosion[3-9]. Therefore, how to maintain or improve the structure and reliability of the road system is a crucial issue, which may benefit not only road users but also be economically beneficial.

Taiwan is located in a subtropical region, the average temperature is about 20°C year-round, however in the summertime road surface temperatures can reach up to 60°C. High temperatures in addition to the impediments of overweight loading and heavy rainfall contribute to frequent road surface deformation and damage in Taiwan. As shown in Fig. 1a-d are four typical damaged forms of road surface in the local area, it can clearly be ascertained that road stripping is the most serious impediment among these road surface damages. According to previous research reports[10-13], water erosion may be one of the main reasons to weaken cohesive force between asphalt mortar and aggregates and final result in the raveling and stripping of the asphalt concrete. There are several ways to decrease the probability of stripping. One way is the use of anti-stripping material in the mixtures, which may increase the cohesive force and stiffness of the asphalt concrete, to reduce the stripping phenomenon resulting from water erosion and temperature variation.

From a road planner's point of view, it may be helpful to analyze the deformed asphalt concrete structure based on various theoretical models and numerical calculations[14-17] and apply these to a specified regional road condition and evaluate it. But from a road practitioner standpoint, these scientific methods are usually limited to only describe the stress-strain relationship of a typical asphalt concrete material, but this is insufficient to explore the characteristics of asphalt concrete mixing with other additives. In contrast, the laboratory test results can be used to understand the characteristics of asphalt concrete mixing with different ingredients and also used to further evaluate the effectiveness of each mixture in preventing possible negative impacts. Hence in this study, three anti-stripping materials include; rock flour, rock flour with lime and rock flour with cement. These anti-stripping materials are investigated through a series of experiments based on the applicable asphalt concrete composition codes for roads.

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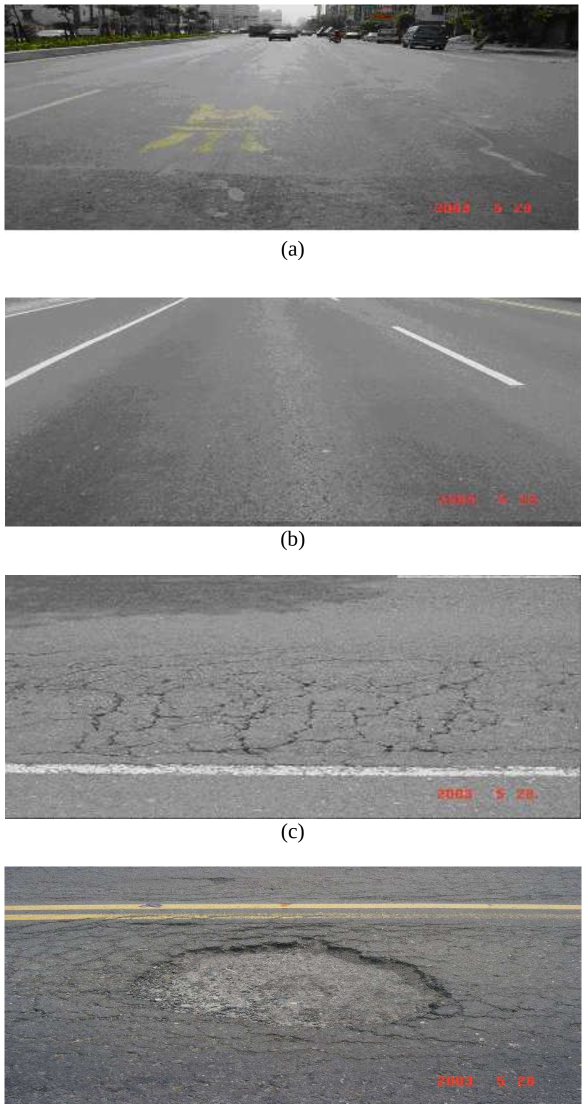

(a)

(b)

(c)

(d)

Fig. 1: Typical damages of asphalt concrete (a) rutting deformation, (b) road surface bleeding, (c) cracking and (d) stripping.

MATERIALS AND METHODS

In order to evaluate the effectiveness of additives in the mixtures of asphalt concrete, a series of experiments according to the codes of ASTM and AASHTO must be performed to determine which filler has a better performance in preventing road surface stripping. In the present study, there are three types of material filler including graded aggregate, asphalt material and mineral filler used for various relative tests as the flow chart displayed in Fig. 2.

It is noted that during theses tests, the aggregates such as rocks and sand are taken from the river bed of the Kaoping River which is located in the southern part of the island of Taiwan. The asphalt mortar with penetration 85/100 is obtained from China Petroleum Company. Besides, the rutting test machine of D200xW50 standard rubber tire with tire pressure 9 kg cm^{-2} is taken to simulate an actual traffic condition.

To compare the performance of different anti-stripping additives, three mineral fillers including rock flour, rock flour with 1% lime and rock flour with 1% cement, added into the asphalt concrete mixture are investigated in this study. The experimental results based on these tests are discussed in the following section.

ANALYSIS OF EXPERIMENTAL RESULTS

At the beginning, the aggregates occupy about 80% to 85% of the total asphalt concrete volume, this is important and may directly affect the quality of paved road surfaces. In accordance with the experimental items as described in a previous section, the aggregates after grain-size sieve analysis has the tested results of Los Angeles abrasion rate 28.16%, soundness 4.03% with the use of Na_2SO_4, coarse aggregate specific gravity 2.618, fine aggregate specific gravity 2.579, coarse aggregate water absorption rate 1.961%, fine aggregate water absorption rate 1.961 and sand equivalent 72%. For the adhesive material asphalt mortar, the basic physical properties have the tested results of penetration 97 (1/10 mm), melting point 45.8°, viscosity 121 (sec, 150°), ductility or extensibility 125^{+} (cm) and specific gravity 1.00 (25°).

The present study uses rock flour as the basic mineral filler in the asphalt concrete mixture; then, by adding 1% of lime or cement to replace the rock flour in the mixture, for evaluating the characteristics of asphalt concrete. Based on the tests, the properties including unit weight, stability value, flow value, void rate and void of mineral aggregate (V.M.A.) of asphalt concrete are shown in Fig. 3-7, respectively.

The unit weight can reflect the compression density of asphalt concrete and the on-site test requires over 95% of the laboratory test value. Usually, the higher the unit weight, the longer the life of asphalt concrete pavement. The curves in Fig. 3 showed that the rock floor exhibits a higher unit weight and the highest value occurred in 5.5% of asphalt content, while the highest value of the other two additives occurred at 6% of asphalt content. For durable and economic concerns, the rock flour seems a better choice, but the difference is small for long term usage.

The stability value represents the ability to resist deformation due to vehicle loading. The curves in Fig. 4 showed that the rock flour with 1% lime can produce a higher rigid road surface at 5.5% of asphalt content, while the rock flour with 1% cement produces a lower stability value despite more asphalt (6%) is required for this case.

The flow value denotes the deformation of asphalt concrete after damage. From the curves of Fig. 5, it can be found that the flow value or the flexibility is in proportion to asphalt content for three additives, but the case of rock flour with 1% lime has a tendency to fit in the code value more suitably.

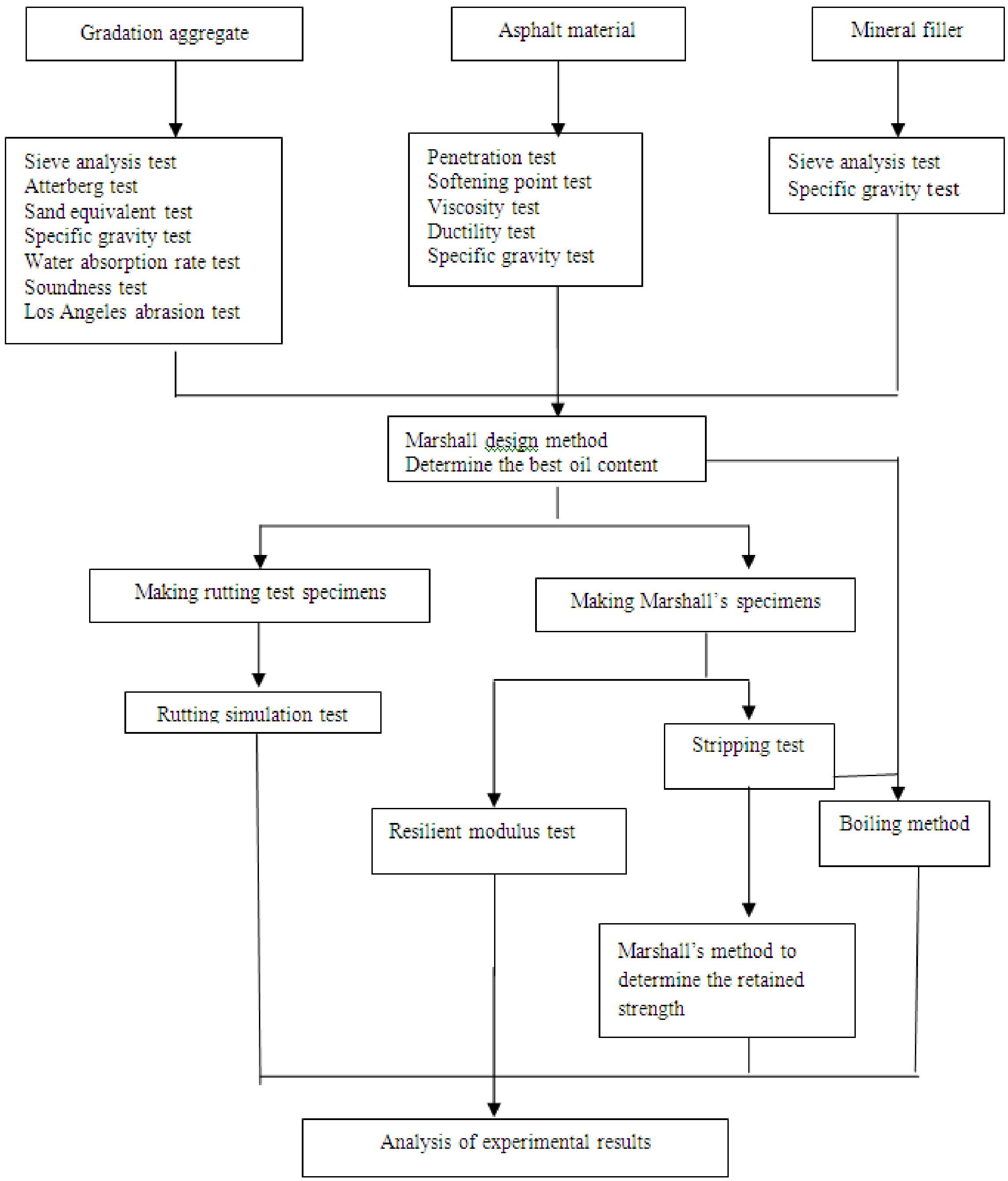

Fig. 2: Flow chart of various tests for asphalt concrete

An adequate flexibility of asphalt concrete may prevent road surface cracking from repeated vehicle loadings.

As the existence of a high void rate in asphalt concrete may cause road surface stripping due to intruding water, road surface bleeding may occur if there is no sufficient void rate in asphalt concrete. Thus, the void rate is important because it can affect the durability of asphalt concrete pavement. In Fig. 6, it can be seen that the void rate is decreased with increasing asphalt content for three additives. Both the cases of rock flour with 1% lime and with 1% cement fillers may slightly increase the void rate, which is good for preventing road surface bleeding and rutting.

As shown in Fig. 7 is the V.M.A. versus asphalt content. The curves showed that the V.M.A. is decreased with increasing asphalt content, after reaching a point, it becomes in proportion to the content of asphalt. The case of rock flour with 1% lime seems to have a higher V.M.A. Which may contain a sufficient amount of asphalt in the mixture to enhance the quality and durability of asphalt concrete pavement.

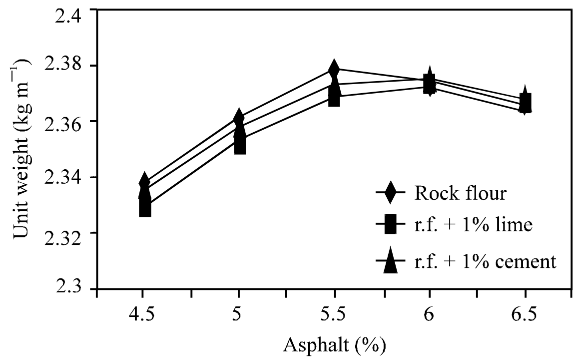

Fig. 3: Unit weight versus asphalt content for the three additives

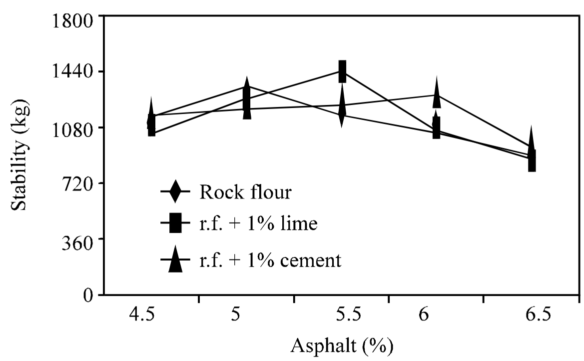

Fig. 4: Stability value versus asphalt content for the three additives

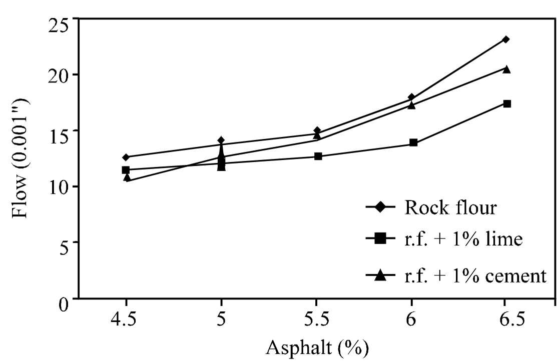

Fig.5: Flow value versus asphalt content for three additives

By taking the data sets of unit weight, stability value, flow value, void rate and V.M.A. Versus asphalt contents and by using a second order regression equation to generate relative curve for each item. The Marshall’s design method employs the regression curves to find the largest unit weight, the largest stability value and the mean void rate. Then, the best oil content of asphalt concrete is determined from the averaged value of asphalt content with respect to the above three items.

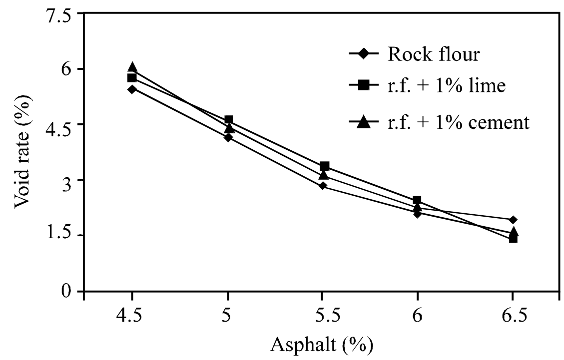

Fig. 6: Void rate versus asphalt content for the three additives

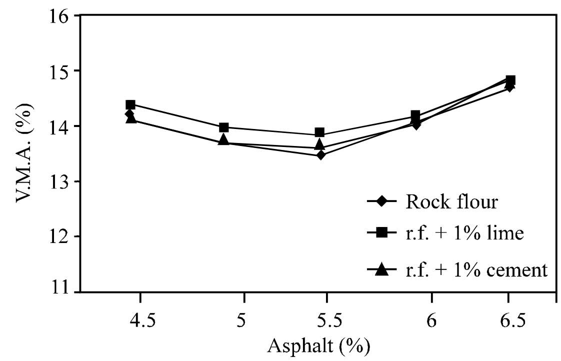

Fig. 7: Void of mineral aggregate versus asphalt content for the three additives

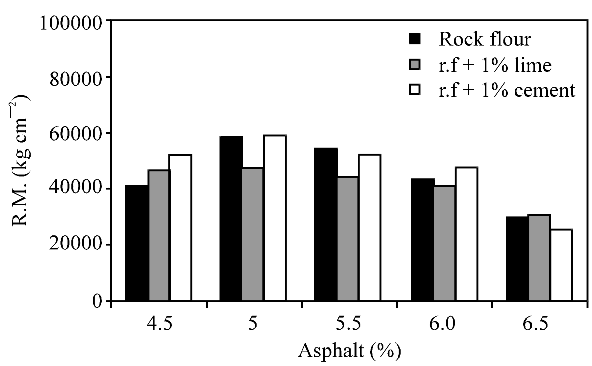

Fig. 8: Resilient modulus for three classes of additives at 10°C

Based on this principle, the Marshall’s design values for each item are displayed in Table 1, which is important to control the quality and construction of the asphalt concrete.

The experimental results exhibited show that all design values for the three cases of additives are fitted in the applicable codes. The case of rock flour with 1% cement has a very small difference in the case of rock flour of the five design values, but the case of rock flour with 1% lime has a higher stability value and a lower flow value among these cases.

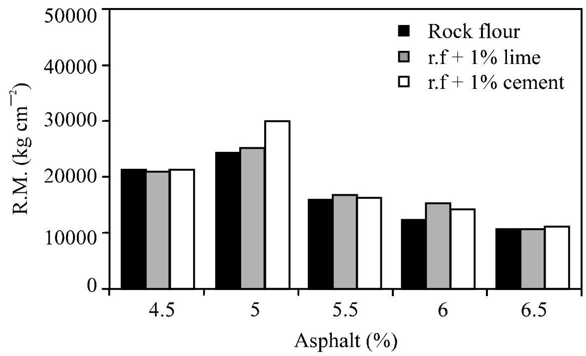

Fig. 9: Resilient modulus for three classes of additives at 25°C

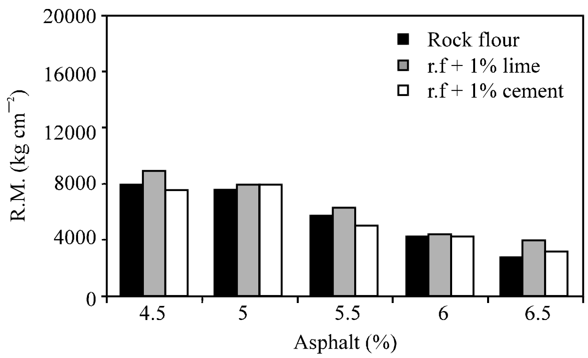

Fig. 10: Resilient modulus for three classes of additives at 40°C

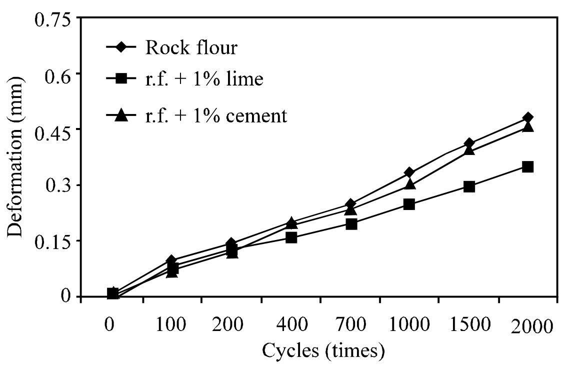

Fig. 11: Rutting deformation for three classes of additives (25°C)

That is, although a little bit higher oil content is required in the case of rock flour with 1% lime as the mineral filler, this case does have a property of higher rigidity and lower flexibility, which implies that this case may increase the durability and usage life for the asphalt concrete road surface.

The resilient modulus test is mainly to measure the elastic deformation of asphalt concrete under different temperatures. An ideal pavement should have a good viscoelastic property (lower resilient modulus) during a relatively low temperature to hold the vehicle loading stress on preventing pavement cracking.

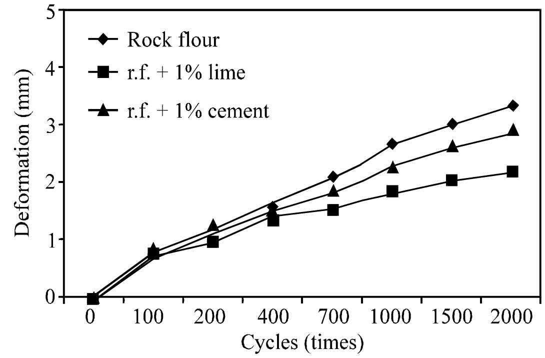

Fig. 12: Rutting deformation for three cases of additives (45°C)

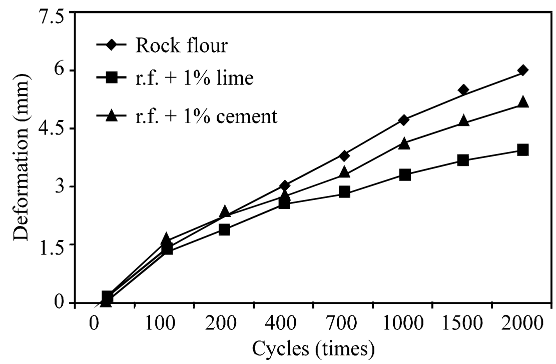

Fig. 13: Rutting deformation for three cases of additives (60°C)

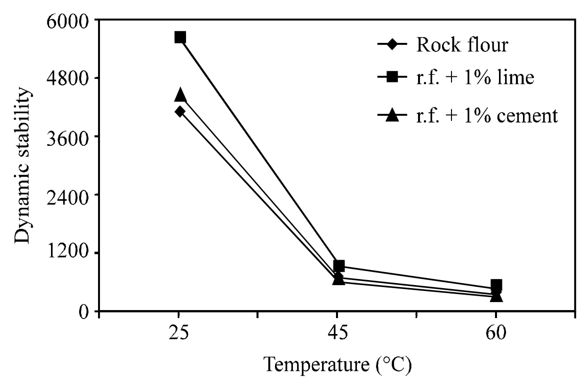

Fig. 14: Dynamic stability (cycle/min) for three cases of additives

Meanwhile, it should have sufficient elasticity (higher resilient modulus) during a relatively high temperature to resist the rutting deformation. Therefore, in this study, the asphalt concrete specimens are tested under temperatures 10, 25 and 40°C, respectively.

From measurements as shown in Fig. 8-10, it can be seen that there is not too much difference of resilient modulus at 25° for the three cases of additives. But at the lower temperature 10°, the case of rock flour with 1% lime tends to have a lower resilient modulus.

Table 1: Marshall's design values for each mineral filler

Items	rock flour	r.f+1% Lime	r.f.+1% cement	codes
Unit weight (kg/m^3)	2.370	2.368	2.372	—
Stability value (kg)	1222	1327	1236	>600
Flow value (0.01")	14.25	13.10	14.23	8~16
Void rate (%)	3.45	3.35	3.43	3~5
V.M.A. (%)	13.70	13.90	13.80	>13
Best oil content (%)	5.3	5.5	5.4	—

Table 2: Fundamental physical tests for each mineral filler

Sieve number (mm)	Percentage of passing weight			
	rock floor	Lime	cement	codes
#30 (0.60)	100	100	100	100
#50 (0.30)	100	100	100	95, 100
#100 (0.15)	98.6	99.2	98.4	—
#200 (0.075)	72.7	92.5	92.1	70, 100
Specific gravity	2.69	2.38	3.15	—
Plastic index	No	—	—	4

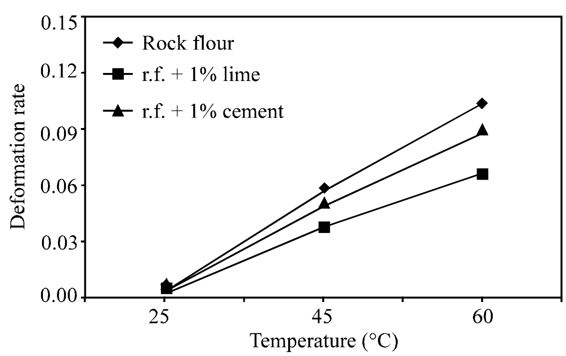

Fig. 15: Rate of deformation (mm/min) for three cases of additives

In addition, it also exhibits a higher resilient modulus at the higher temperature 40°. That is, this filler in the asphalt mixture can achieve a better performance either at low temperature or at high temperature.

In the Taiwan area, the average road surface temperature in the winter season is about 25°, but in the summer season, it will rise up to 60°, which is over the melting point 45° of asphalt mortar. As asphalt concrete is a temperature sensitive material, rutting deformation is one of the primary reasons to cause road damage in Taiwan. Thus, it is necessary to check the pavement deformation due to vehicle tire loadings.

Basically, there are three types of rutting deformation; consolidation rutting, lateral plastic movement and mechanical deformation are found in practice. As the experiment results in Fig. 11, show the consolidation deformation should be the type of temperature equals to 25°. As the temperature reaches 45° and as shown in Fig. 12, in addition to the consolidation deformation, the lateral movement may also be occurring in this case because of the approaching melting point. As the temperature becomes 60°, the result in Fig. 13 showed that multiple types and much more rutting deformations may be existed at this high temperature.

In three cases of additives, because the rock flour with 1% lime may decrease the flow rate and increase the stiffness of asphalt concrete, this test proved that this case can generate a lower rutting deformation in each temperature condition. To further enhance this statement, by calculating the slope of a straight line from the curve of the cycle and deformation and by taking the ratio of deformation and rolling time, the dynamic stability and the rate of deformation for the three additives are displayed in Fig. 14 and Fig. 15.

The curve of dynamic stability has a similar tendency for three additives, but it decreased rapidly at temperature 45°. The case of rock flour with 1% lime has a higher dynamic stability value, which may have a better ability against the rutting deformation. In addition, the rate of deformation exhibits very small differences at temperature 25° in the three cases of additives, but the difference becomes more significant for the higher temperatures. The results also show that the case of rock with 1% lime may have a better ability against the rutting deformation as it has a smaller rate of deformation.

Because the degree of stripping for asphalt concrete can be varied with different additives, in this study, the Marshall's retained strength method and the boiling method are used to check the anti-stripping capability of the additives. According to the best asphalt content to make asphalt concrete specimens with different additives, the Marshall's test showed that the retained strengths are 86.2%, 96.0% and 92.9% for rock flour, rock flour with 1% lime and rock flour with 1% cement, respectively. All three cases pass the code requirement (75%), but it is clear to see that the case of rock flour with 1% lime has a higher retained strength and thus may provide a better performance in preventing road surface stripping.

The boiling test is a simple way to check the phenomenon of asphalt concrete stripping, but the drawback of this method is the man-made errors. To reduce the errors in this observation test, the present results are obtained from the averaged value of three persons and the percentages of wrapped asphalt in the grains are 95.7, 99.8 and 98.3% for rock flour, rock flour with 1% lime and rock flour with 1% cement, respectively. This test also verified that the case of rock flour with 1% lime can increase the ability of anti-stripping.

From the above experimental results, it may conclude that the case of rock flour with 1% lime is a better choice for using in asphalt concrete mixture. But why is lime relatively more effective than cement? By analyzing the fundamental physical properties of each additive as seen in Table 2, it can be found that the lime has the smallest specific gravity and the large percentage rate in each sieve number. That is, the relatively lighter unit weight, larger fineness and rougher grain surface of lime may fill in the void of asphalt mortar more densely. Therefore, it exhibits a better performance in several items of experimental results.

Surely, one may argue that the case of rock flour with 1% cement has also a similar effect as the difference is small and is within the range of the standard deviation. The statistical methods and a long term on-site evaluation may be used to assess the true variation in effect. However in practice, both fillers are cheap and can easily be used in resisting asphalt concrete stripping, the lime seems to perform slightly better at least in the present laboratory work results.

CONCLUSION

Based on the applicable codes, a series of experiments have been conducted in this study to evaluate the effectiveness of anti-stripping materials with the mixture of asphalt concrete. Three cases of additives including rock flour, rock flour with 1% lime and rock flour with 1% cement were analyzed to make comparisons. The experiment results have shown that in the conventional mineral filler such as rock flour, the addition of lime or cement in the mixture did have the advantages of increasing the viscoelastic property and the stiffness and compactness to reduce negative impacts on the asphalt concrete road surface.

In particular, by adding 1% of lime in the rock flour as the filler, several positive data could be obtained including:

1. A higher stability value,
2. A lower flow value,
3. A higher retained strength,
4. A higher percentage of wrapped asphalt in the grains,
5. A lower resilient modulus in low temperature (10°) but a higher value in high temperature (40°),
6. A higher dynamic stability and
7. A lower rutting deformation rate.

These results might have proved that the case of rock flour with 1% lime could increase the abilities of anti-stripping and resist the rutting deformation and thus might increase the durability and usage life of the asphalt concrete road surface.

The present experimental study has been limited to the case of adding 1% anti-stripping material in the asphalt mixtures. The results have shown that it did have a better performance than the conventional type of fillers, but the evaluation of including different percentages of additives in the mixtures was not considered here. Additionally, the results of this study were obtained in the laboratory, which might require long term on-site tests to examine the difference and to further check the usefulness of each test. Above all, the present study has complied with the applicable codes, and previous research based on the topic of preventing road surface damages. The results might provide a useful reference when constructing a road with regional characteristics similar to Taiwan's.

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