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Influence of Active Filler, Curing Time and Moisture content on the Strength Properties of Emulsion and Foamed Bitumen Stabilized Mix

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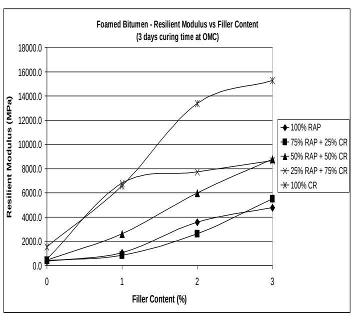
Graphical abstract



Abstract

Foamed bitumen and emulsion are common stabilizing agents that are currently used for recycled asphalt pavement construction throughout the world. The strength of stabilized Reclaimed Asphalt Pavement (RAP) is influenced by factors such as filler content, moisture level and curing time. This paper describes the strength impact of ordinary Portland cement as active filler, the length of the curing time and moisture content on the foamed bitumen and emulsion stabilized mix. The basic objective of the paper is to evaluate the effect of active filler (Ordinary Portland Cement), curing time and moisture content on the strength of foamed bitumen and emulsion treated mix. The foamed and emulsion treated samples with various contents of RAP and crushed stone aggregates were tested for their strength properties. The resultant strength increases in terms of resilient modulus, Unconfined Compressive Strength (UCS) and the Indirect Tensile Strength (ITS) values, were correlated with the length of curing time, using various percentages of active filler and proportions of RAP in the pavement mix. It was found that the strength decreased with increased RAP content, however if 100% RAP is to be used then the required pavement strength can be achieved by utilizing a higher active filler ratio. The effect of moisture content variation on foamed bitumen and emulsion treated samples with high percentage of RAP is not significant.

Keywords: Foamed bitumen; emulsion; filler, recycled asphalt pavement.

1.0 INTRODUCTION

1.1 Background

The term Bitumen Stabilized Material (BSM) was used in South Africa for foamed bituminous mixes. BSM has been in use in South Africa for more than 10 years. A tentative guideline document was published in 2002 by the Asphalt Academy [1, 2].

Cold recycling technology with foamed bitumen is economical, sustainable and environmentally friendly [3, 4]. Foamed bitumen can be used to stabilize a variety of materials, including the RAP materials. From both economic and ecological points of view cold recycling technology is much more beneficial than hot mix asphalt [5].

The Cold-In-Place Recycling (CIPR) technique was first introduced in Malaysia around the mid 80's. Since then, the concept of recycling road pavements as an alternative rehabilitation measure has become popular and acceptable [6, 7].

The technique involves recycling of all the asphalt pavement section and a portion of the underlying materials with an addition of stabilizing agents to produce a stabilized base course. The advantages of the CIPR include cost savings of up to 40 percent over conventional techniques and the benefits associated with material recycling [8, 9].

Research works by Cooley [10] have shown that the performance of the recycled asphalt layer depends on the proportion of reclaimed asphalt pavement (RAP), types of stabilizing agents, and amount of active filler. For the purpose of this paper, active filler is referred to Ordinary Portland Cement (OPC).

Although the CIPR technique is gaining acceptance as a cost effective solution in rehabilitating distressed pavement [11, 12], very little local research has been carried out on its cost effectiveness, design, construction and long term performance. Subsequently, the Public Work Department (PWD) has embarked on a research program in this field, in collaboration with Kumpulan Ikram and Roadcare Sdn. Bhd. as the basis of the establishment of Malaysian Guidelines for CIPR Design and Construction.

1.2 Objective

The aim of this paper is to highlight the effect of active filler, curing time and moisture content on the strength properties of foamed bitumen and emulsion treated mix, through the following objectives:

- To evaluate the effect of active filler on the strength of foamed bitumen mix.
- To appraise the effect of moisture content on the strength of foamed bitumen mix.

■2.0 EXPERIMENTAL/METHODOLOGY

2.1 Experimental Matrix and Sample Preparation

In the study, foamed bitumen and emulsion treated samples with different proportions of RAP and crushed stone aggregates (CR) were tested for their strength properties at various active filler contents, curing time and moisture contents. Table 1 summarizes the experimental matrix used in the study involving five different RAP proportions which represent the possible combinations that may be encountered during construction. The test matrix is therefore designed to investigate the expected field performance for these different mixture compositions.

Samples for ITS and Resilient Modulus test (100 mm briquettes) were prepared in accordance to Marshall test method with modifications to the compaction temperature and curing procedures. Samples for UCS test (150 mm diameter) were prepared in accordance to Modified Proctor BS 1377.

In order to analyze the effect of active filler on the strength properties, samples were mixed at optimum moisture content (OMC) as determined by the modified Proctor test method (BS 1377) and dry cured for 3 days. To determine the curative period for the samples to reach the required strength, the samples were dry cured for 1,2,3,7 and 28 days using 1% active filler at OMC. To study the effect of varying moisture content on the strength properties, the active filler was set constant at 1% and samples were dry cured for 3 days.

Table 1 Experimental matrix and specimen quantities

Aggregate Proportion	Strength Test	Curing Time (Day)					Moisture Content (%)					Active Filler (%)			
		1	2	3	7	28	-30	-15	OMC	+15	+30	0	1	2	3
		Sample Quantities													
100% RAP	UCS	3	3	3	3	3	3	3	3	3	3	3	3	3	3
	ITS	3	3	3	3	3	3	3	3	3	3	3	3	3	3
	R.Modulus	3	3	3	3	3	3	3	3	3	3	3	3	3	3
75% RAP + 25% CR	UCS	3	3	3	3	3	3	3	3	3	3	3	3	3	3
	ITS	3	3	3	3	3	3	3	3	3	3	3	3	3	3
	R.Modulus	3	3	3	3	3	3	3	3	3	3	3	3	3	3
50% RAP + 50% CR	UCS	3	3	3	3	3	3	3	3	3	3	3	3	3	3
	ITS	3	3	3	3	3	3	3	3	3	3	3	3	3	3
	R.Modulus	3	3	3	3	3	3	3	3	3	3	3	3	3	3
25% RAP + 75% CR	UCS	3	3	3	3	3	3	3	3	3	3	3	3	3	3
	ITS	3	3	3	3	3	3	3	3	3	3	3	3	3	3
	R.Modulus	3	3	3	3	3	3	3	3	3	3	3	3	3	3
100% CR	UCS	3	3	3	3	3	3	3	3	3	3	3	3	3	3
	ITS	3	3	3	3	3	3	3	3	3	3	3	3	3	3
	R.Modulus	3	3	3	3	3	3	3	3	3	3	3	3	3	3

* 3 denote number of specimen

2.2 Description of Materials

Table 2 shows the gradation, optimum fluid content (OFC), maximum dry density (MDD) and optimum binder content (OBC) of the samples for each RAP proportions. The gradation and composition of the samples represent typical values obtained from recycling projects throughout the country. Strength tests such as ITS, UCS and resilient modulus were carried out on each RAP proportion shown in Table 2 and the average result obtained from three samples for each proportion are reported. The test results would simulate the actual performance of the recycled layer.

From Table 2, it can be seen that the Optimum Fluid Content, a combination of water and binder, increases as the RAP content decreases since more fluid is required to pack the aggregate to its maximum density due to the presence of higher percentage of fines. The OBCs were determined at the highest ITS values for each mix proportion. For foamed bitumen stabilized samples, the OBC was 1.5% for samples with 100% RAP and 3% for the other samples. For emulsion stabilized samples, the OBC was 4% for samples with 100% and 75% RAP and 6% for the other samples.

It was also observed that the recycled material (100% RAP) has less fines than the normal crushed aggregate which is due to the conglomeration of fines in the RAP binder.

Table 2 Material gradation, OFC, MDD, OBC

Grading Sieve Size (mm)	Aggregate Proportion (% Passing)				
	100% RAP	75%RAP + 25%CR	75%RAP + 25%CR	25%RAP + 75%CR	100%CR
50	100	100	100	100	100
37.5	100	99.5	99	98.5	97
20	93.8	89.5	85.5	82	78
10	71	69	66	63	60
5	45.3	45	45	45	45
2.36	26.4	28	29	31	32.11
0.425	2.2	7	9.5	12	13.71
0.075	0.4	3	4.5	5	6.91
OFC (%)	4.81	5.14	5.82	6.08	6.13
MDD (Mg/m^3)	1.879	2.024	2.161	2.281	2.253
OBC Foamed Bitumen (%)	1.5	3	3	3	3
OBC Emulsion (%)	4	4	6	6	6

3.0 RESULTS AND DISCUSSION

3.1 Unconfined Compressive Strength (UCS) Test

3.1.1 UCS vs. Curing Time

Both foamed bitumen and emulsion stabilized samples showed similar results as displayed in Figures 1 and 2. The UCS values increased with curing time depending on the percentage of RAP and type of stabilizing agent. There was a rapid increase in UCS within the first 5 days of curing for all samples, after which the increase was gradual. Generally it was observed that higher RAP proportion resulted in lower UCS values.

In the local construction practice, the UCS requirement for recycling works is specified at 0.7MPa for a 7-day curing period [5]. However, the protection and maintenance period before overlaying with the asphaltic layer is only 2 days. For foamed stabilized samples, all samples achieved the required strength as early as 2 days except for the 100% RAP. At 100% RAP, the UCS value did not meet the minimum requirement of 0.7MPa at 7 days, however, it was achievable at 28 days curing time. In order for the treated road to be opened for traffic after 2 days it is recommended that the maximum RAP content be set at 75%. It is worth noting that, samples with 0% to 50% RAP achieved the 0.7MPa requirement as early as 1 day.

For emulsion stabilized samples, only the samples with 0%-25% RAP met the UCS requirement after 2 days. The 50% RAP sample reached the requirement at 3 days, whilst the 75% RAP achieved the required strength only at 12 days. The 100% RAP sample did not meet the required strength even after 28 days of curing.

These observations suggest that at 1% active filler, the time taken to open the treated road to traffic depends on the RAP proportions. Consequently, higher active filler content may be necessary to shorten the curing time in cases where it requires early opening to traffic.

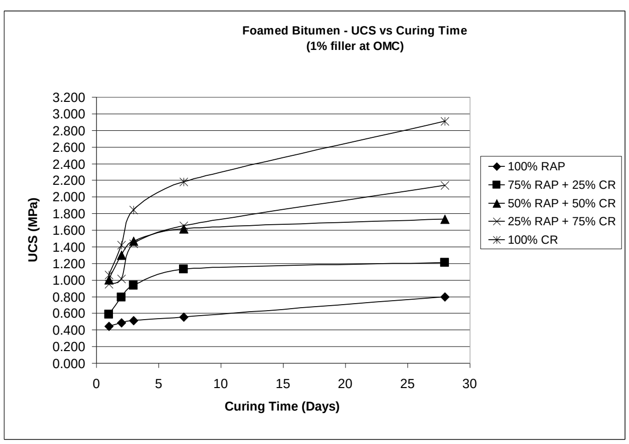


Figure 1 Foamed Bitumen- UCS vs curing (1% filler at OMC)

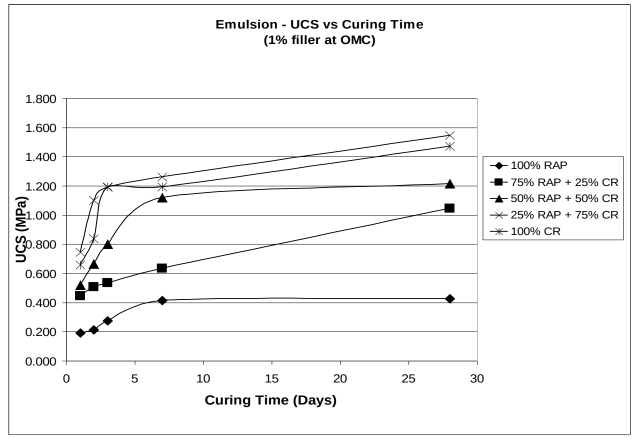


Figure 2 Emulsion- UCS vs curing (1% filler at OMC)

3.1.2 UCS vs. Active Filler Content

For both foamed bitumen and emulsion treated samples that contained RAP, the required strength of 0.7MPa could not be achieved without the inclusion of active filler. The results of foamed and emulsion bitumen UCS against the filler content is illustrated in Figures 3 and 4 respectively. The results indicated that the active filler is vital in recycling works in Malaysia involving the use of RAP. It was also found that the UCS increases with the active filler content.

For foamed bitumen treated samples, except for 100% RAP, all other combinations of RAP satisfied the strength requirement when a minimum of 1% active filler was added. For the 100% RAP samples a minimum of 2% active filler was essential to attain the required strength.

For emulsion treated samples with 100% RAP, a minimum of 3% active filler was needed to achieve the required strength. Samples with 75% RAP required 1.5% active filler, whilst those with 50% RAP needed only 1% active filler.

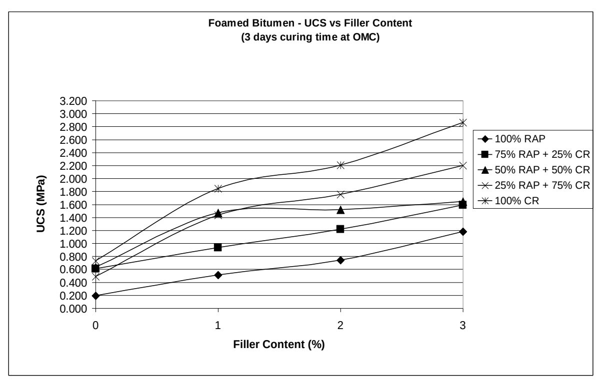


Figure 3 Foamed Bitumen- UCS vs Filler Content (3 days curing time at OMC)

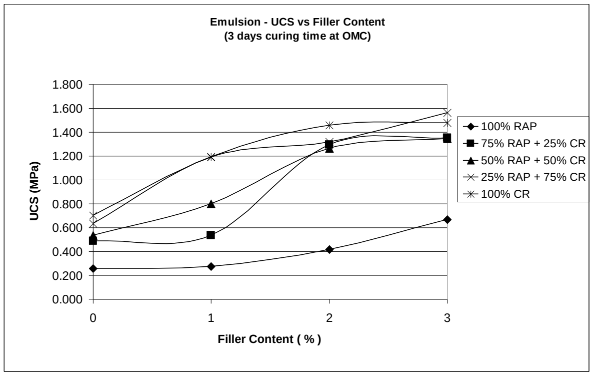


Figure 4 Emulsion- UCS vs Filler Content (3 days curing time at OMC)

3.1.3 UCS vs. Moisture Content

UCS is also influenced by the moisture content which is critical for compaction. All foamed bitumen treated samples consistently showed the highest UCS values occurring at OMC as shown in Figure 5. A similar trend was not observed for the emulsion treated samples where the highest UCS values did not necessarily occur at OMC as indicated in Figure 6. It was found that variations in moisture content within ±30% of OMC did not affect the UCS values significantly for both types of treatment. This confirms findings by other research works [2, 12] that mixing can be done in the range of 65-85% of the OMC. It is a common practice in Malaysia to lay and compact the foamed bitumen and emulsion treated layer at ±20% of OMC. The results also showed that UCS is a poor indicator of moisture sensitivity of treated samples. Similar conclusion has been suggested by Houston [4].

It was also observed that 0% RAP samples achieved higher UCS strength within the studied range of moisture content. This may be due to the presence of higher fines content in the crusher run which contributed to the strength

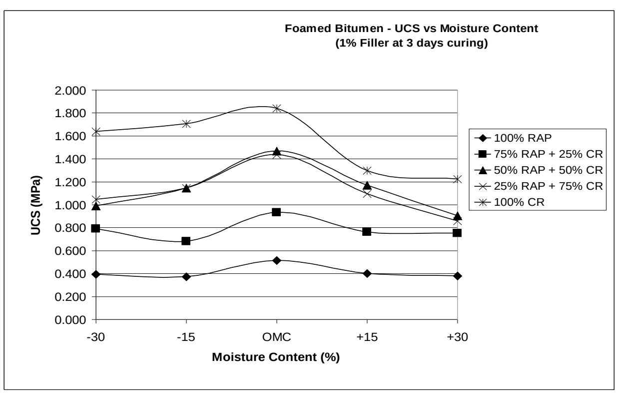


Figure 5 Foamed Bitumen- UCS vs Moisture Content (1% filler at 3 days curing time at OMC)

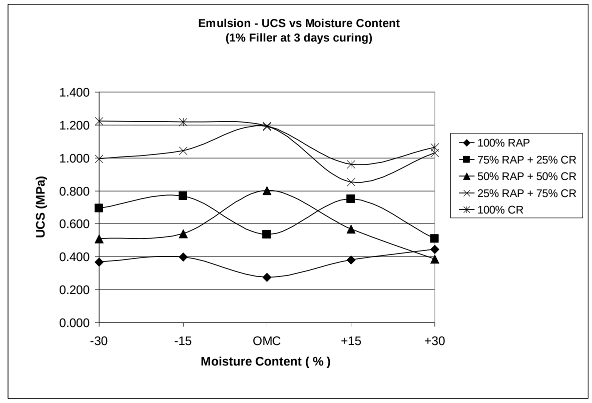


Figure 6 Emulsion- UCS vs Moisture Content (1% filler at 3 days curing time at OMC)

3.2 Indirect Tensile Strength (ITS) Test

3.2.1 ITS vs. Curing time

The ITS values were observed to increase with curing time. There was a rapid increase in ITS within the first 5 days of curing for all samples, after which the increase was gradual as displayed in Figures 7 and 8. For foamed bitumen treated samples, the 75% RAP and 100%RAP did not achieve the required value of 200kPa at 3 days, whilst for the emulsion treated samples only 100% RAP did not achieve the required strength at 3 days. The results did not seem to indicate positive correlation between RAP proportions and ITS values. This was unexpected, as the authors anticipated the trend to be similar to that of the resilient modulus against curing time, since both testing methods investigate the shear parameters of the samples.

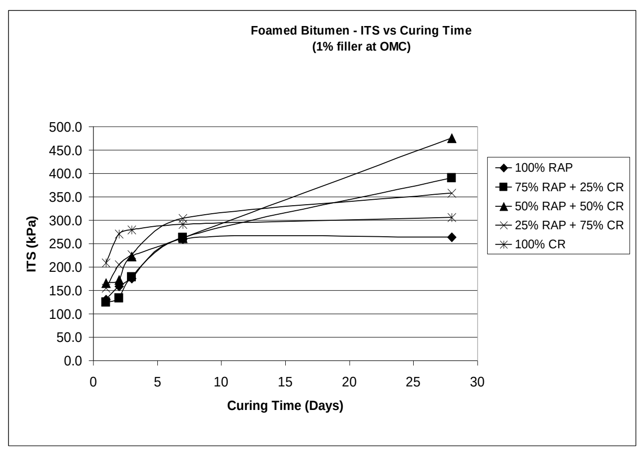


Figure 7 Foamed Bitumen- ITS vs curing time (1% filler at OMC)

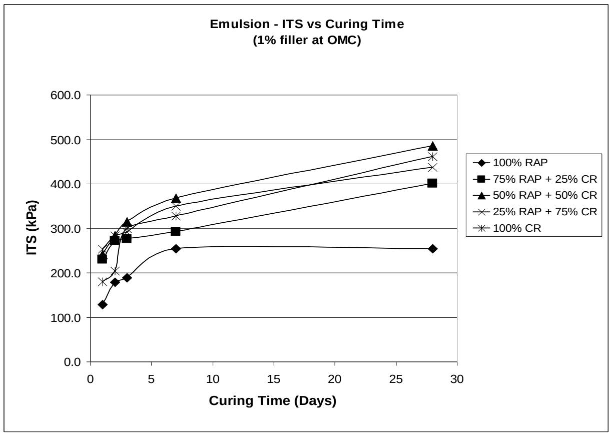


Figure 8 Emulsion- ITS vs curing time (1% filler at OMC)

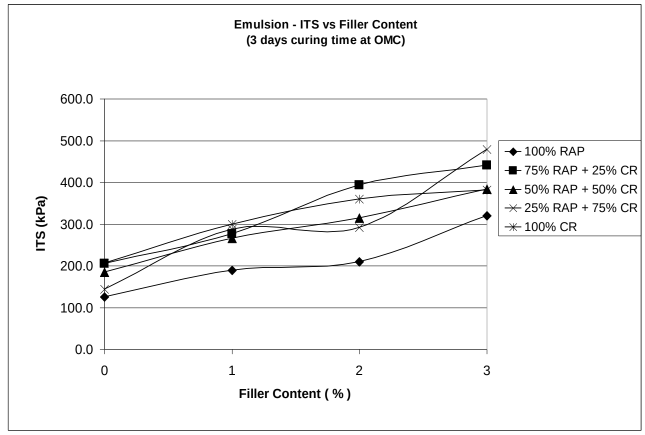


Figure 10 Emulsion- ITS vs Filler Content (3 days curing time at OMC)

3.2.2 ITS vs. Active Filler Content

Generally the ITS values increase with the amount of active filler as displayed in Figures 9 and 10. The minimum filler content to achieve the required 200kPa varied for different RAP proportions and stabilizing agents. As an example for foamed bitumen treated samples, 1.5% of active filler content was sufficient for 100% RAP, whereas no filler was required for the 0% RAP. For emulsion treated samples, 1.5% of active filler was also sufficient for 100% RAP while a nominal amount of 0.3% active filler was required for the 25% RAP.

3.2.3 ITS vs. Moisture Content

The ITS values are also influenced by moisture content. Similar to the UCS test, the maximum ITS was expected to occur at the OMC since the sample achieved the highest density at this moisture level. However, this was not reflected in the results. Except for the 50%RAP samples which achieved the maximum ITS values at the OMC, most of the other samples did not indicate a distinct maximum ITS value within the moisture content investigated. The ITS results against moisture content is shown in Figures 11 and 12.

For foamed bitumen treated samples with higher RAP content, variation in the moisture content did not affect ITS values significantly. However, for low RAP proportions of 25% RAP and below, the ITS values increased when the moisture content decreased. For the emulsion treated samples, there was generally no specific pattern linking the ITS and the moisture content.

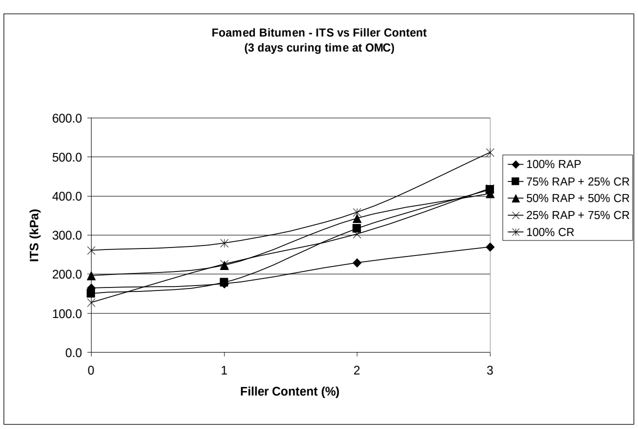


Figure 9 Foamed Bitumen- ITS vs Filler Content (3 days curing time at OMC)

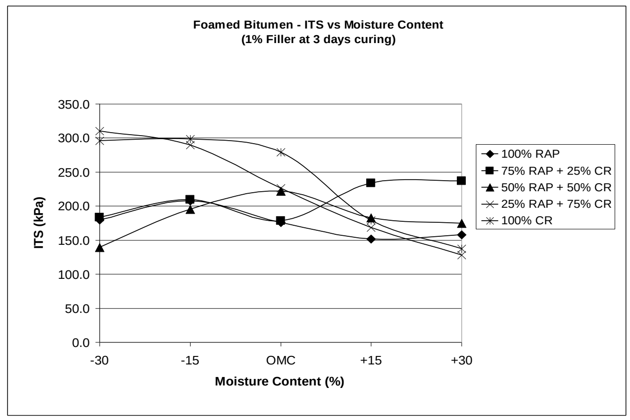


Figure 11 Foamed Bitumen- ITS vs Moisture Content (1% filler at 3 days curing time at OMC)

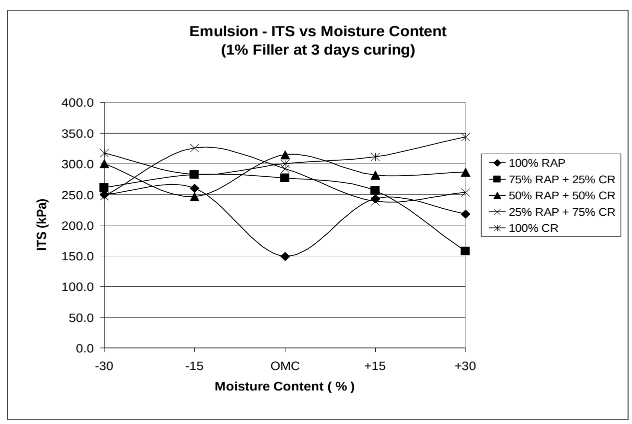


Figure 12 Emulsion- ITS vs Moisture Content (1% filler at 3 days curing time at OMC)

3.3 Resilient Modulus

3.3.1 Resilient Modulus vs. Curing Time

There was a rapid increase in resilient modulus within the first 5 days of curing for all samples as can be seen in Figures 13 and 14, after which the increase was gradual. It was also observed that the higher RAP proportion resulted in lower resilient modulus. For foamed bitumen and emulsion treated samples containing higher

RAP proportion of 75% and 100% RAP, a longer curative period was required to achieve the required value of 2000MPa. As an example, the foamed bitumen treated samples with 100% RAP needed 10 days, whilst the emulsion treated sample with 100%RAP could not achieve the required strength at 28 days. This suggests that higher active filler content shall be used to shorten the curative period in cases where it requires early opening to traffic.

3.3.2 Resilient Modulus vs. Active Filler Content

The resilient modulus increases with an increase in active filler content as displayed in Figures 15 and 16. It was observed that for foamed bitumen treated samples with 75% and 100% RAP, a minimum of 1.5% active filler content was necessary to achieve the resilient modulus value of 2000MPa at 3 days. This is in line with the construction practice in Malaysia of using 1.5% active filler for foamed bitumen recycled base.

For emulsion treated samples, it was found that more than 3% active filler may be required for 100% RAP to achieve the 2000MPa resilient modulus at 3 days. For 75% RAP, 1.2 % active filler was sufficient.

3.3.3 Resilient Modulus vs. Moisture Content

The variation of the moisture content did not affect the resilient modulus values of samples with high RAP content. For foamed bitumen treated samples with less RAP proportions, the modulus peak at certain moisture content. The results in Figure 17 showed that at 1% active filler, samples with high RAP content of more than 50% did not meet the resilient modulus of 2000MPa, a value normally assumed in pavement design. For samples with low RAP contents, the resilient modulus at their respective OMC could be as high as 6000 MPa. Therefore it is suggested that the seed values to be used in pavement design for RAP layer be based on the modulus of the corresponding RAP proportions.

For emulsion treated samples with 100% RAP, the resilient modulus was slightly below 2000MPa within the studied moisture content as shown in Figure 18. For the 75% RAP, the resilient modulus was higher than 2000MPa at moisture content lower than OMC.

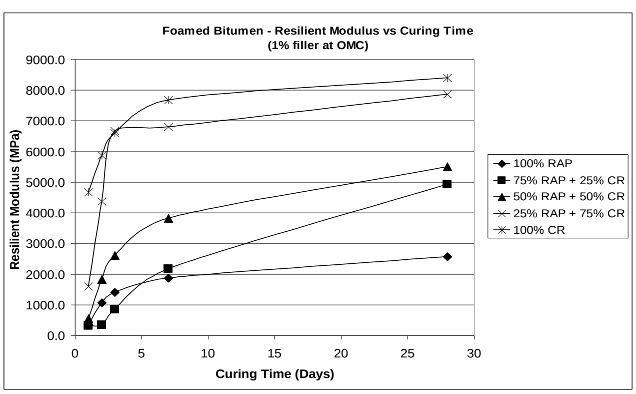


Figure 13 Foamed Bitumen- Resilient modulus vs curing time (1% filler at OMC)

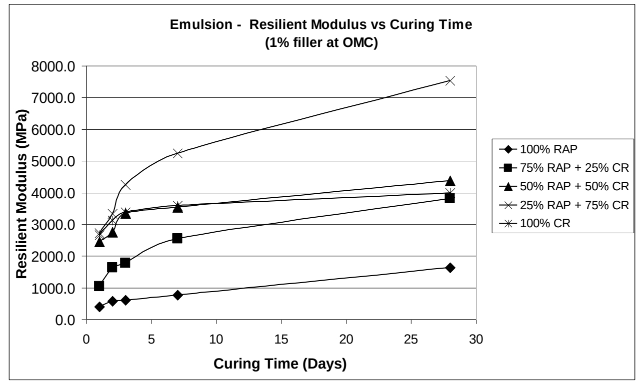


Figure 14 Emulsion- Resilient modulus vs curing time (1% filler at OMC)

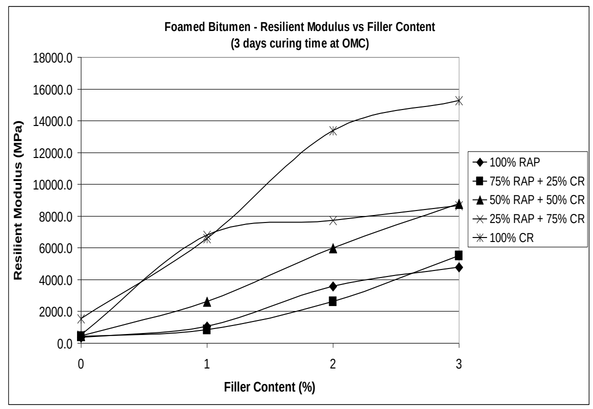


Figure 15 Foamed Bitumen- Resilient modulus vs Filler Content (3 days curing time at OMC)

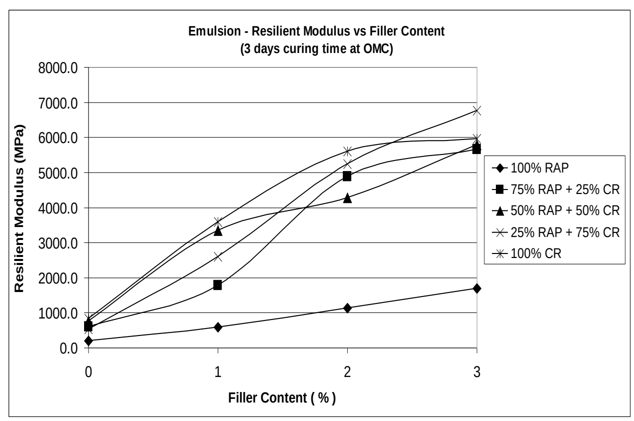


Figure 16 Emulsion- Resilient modulus vs Filler Content (3 days curing time at OMC)

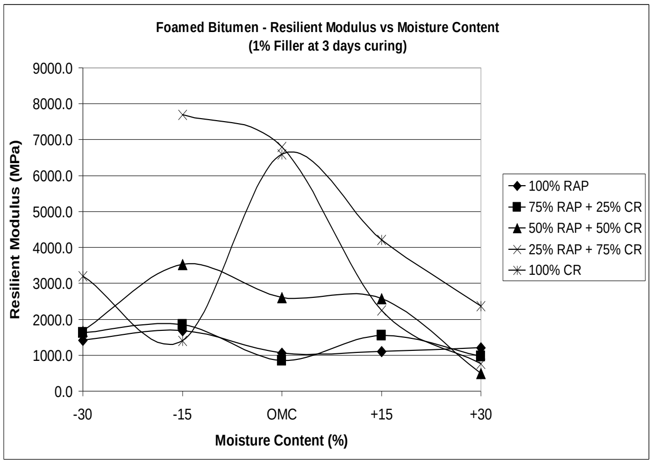


Figure 17 Foamed Bitumen- Resilient modulus vs Moisture Content (1% filler at 3 days curing time at OMC)

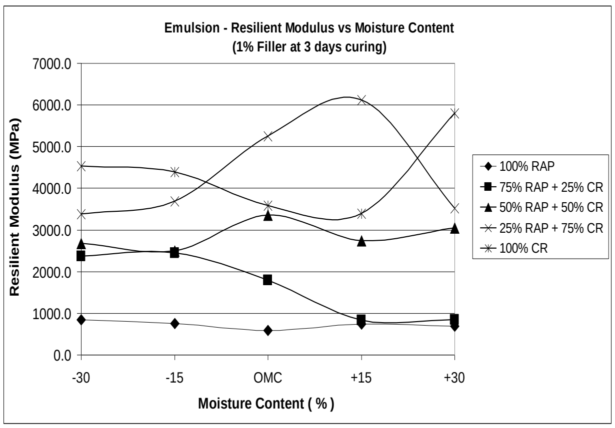


Figure 18 Emulsion- Resilient modulus vs Moisture Content (1% filler at 3 days curing time at OMC)

■4.0 CONCLUSION

Based on the study, active filler content, curing time, moisture content, and RAP proportions are contributing factors to the performance of recycled asphalt layers in the CIPR works utilizing foamed bitumen and emulsion as the stabilizing agents. It can be concluded that active filler is required in recycling works in Malaysia. At 1% active filler the curative period is 3 days provided the RAP proportion is not more than 50%. For 75% RAP, 1.5% active filler is recommended. For 100% RAP, the minimum active filler for CIPR with foamed bitumen and emulsion is 2% and 3% respectively. The effect of moisture content variation on foamed bitumen and emulsion treated samples with high RAP proportion is not significant. For low RAP proportion samples, higher ITS and resilient modulus values were recorded at lower moisture content.

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