COLD IN-PLACE RECYCLING OF MARGINAL MATERIALS IN MALAYSIA: HOW DOES IT FARE?

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ABSTRACT

In the early 1980s, a major part of the road networks linking dwellers in oil palm plantation consisted of laterite and crushed aggregate materials. These roads initially carried low traffic volume with less than 1,000 vehicles per day which includes heavy vehicles carrying palm fruits and timber logs. With the increase in infrastructure development, these roads underwent upgrading as well. It is a common practice in Malaysia to upgrade this type of road by introducing granular base course and asphaltic concrete overlay. However, recently the use of in-situ recycling technique has been introduced to upgrade the existing marginal materials to an acceptable quality as part of a comprehensive study on full depth Cold in-Place Recycling (CIPR). Various stabilizing agents such as foamed bitumen, emulsion, ordinary Portland cement and hydrated lime were used in the CIPR technique.

This paper describes pavement evaluation and structural design processes, mix design and construction methods, and presents the performance test results for two project sites, namely Felda Pekoti Timur and Felda Krau, in Pahang, Malaysia.

1.0 INTRODUCTION

1.1 Background

Malaysia is relatively a small country of 14 states, which are linked by about 100,000 kilometres of paved roads, 16,000 kilometres of gravel roads and 8,000 kilometres of earth roads [1]. Pahang being the third largest state in Malaysia has almost 1,200 km of gravels and earth/laterite roads. The geography of Pahang can be categorized into the highlands, rainforest and coastal areas. Most of the major plantation areas can be found in the countryside, close to the rainforest area. With the increase in development particularly in plantation area, the need to have a better road network linking the dwellers has become a necessity. The use/reuse of locally available materials or marginal materials was one of the options being considered. Marginal materials refer to naturally occurring road making materials which include alluvial or colluvial sands and gravels, pyroclastic tuffs and scorias, and chemically formed gravels such as calcretes and laterites [2]. The use of this marginal materials is in view of the hauling cost of new construction materials over long distance to low volume roads can be costly. Moreover, the scarcity of quarried materials and the environmental impact of using fresh material is also one of the main concerns.

Since mid 1980's when the Cold in-Place Recycling (CIPR) technique was first introduced in Malaysia, the concept of recycling road pavements as an alternative rehabilitation measure has become popular and acceptable. The recycling technique is a process where the existing materials are mixed and processed together to produce a stabilized base course. The mixed materials are recycled and additives are introduced; materials are then shaped and compacted before asphalt surfacing is applied [3]. Although the CIPR technique is gaining acceptance as a cost effective solution in rehabilitating distressed pavement, no local research has been carried out to study its cost-effectiveness, design, construction methods and performance of CIPR on marginal materials. The Public Works Department (PWD) in collaboration with Kumpulan Ikram and Roadcare Sdn. Bhd. has embarked on a research work to look into the performance of recycling on marginal materials as part of a comprehensive study on full depth CIPR technique. It is hoped that this study will lead to an establishment of a comprehensive design and construction guidelines on CIPR for Malaysia which not only covers the asphaltic pavement but also on marginal materials.

1.2 Objectives

The objective of this paper is to highlight the ongoing research work and present early findings of the research in terms of the observed performance of recycled marginal materials with various stabilizing agents used, namely cement, lime, emulsion and foamed bitumen. The paper describes the tests and methodology involved as well as the parameters used to evaluate the performance of the pavements. A comparison on the performance and cost-effectiveness amongst different recycling and conventional rehabilitation techniques/methods are also presented.

2.0 METHODOLOGY

2.1 Research Sites

Federal Route Felda Pekoti Timur (Site 1) and FT 1502 Felda Krau (Site 2), both located in the state of Pahang has served the dwellers under the Federal Land Development Scheme. Traffic volume was relatively low with an average daily traffic of less than 1,000 vehicles, with heavy vehicles make up about 45 percent. Major activity around these areas involves palm fruit plantation and timber logging, which causes trucks or trailers to ply these routes regularly to get to the nearby factories.

2.2 Pre-construction conditions

Since the two sites consist of combination of laterite and gravel roads, Falling Weight Deflectometer (FWD) test and International Roughness Index (IRI) measurement were not carried out prior to construction stage. Based on the visual surface condition survey, several localized sections had recorded depression of more than 40mm. From Dynamic Cone Penetrometer (DCP) test, Subgrade's California Bearing Ratio (CBR) was found to be ranging from 6% to 16% during the dry season. **Figure 1** and **Figure 2** depict the photos taken from the two sites.

Figure 1 - Felda Pekoti Timur **Figure 2 - Felda Krau**

Each research site was divided into five (5) 200m sections. Four sections were treated with CIPR method utilizing four different stabilizing agents, whilst a control section was treated using conventional overlay with granular and asphaltic layers. For the purpose of this study, both sites will be monitored for five years with no necessary maintenance or repair work attended.

2.3 Pavement Structural Design

A standard single axle load of 8.16 tones was adopted in the calculation of Equivalence factor (E.F) for each axle configuration. Based on the axle load survey, an E.F value of 2.7 and 3.0 were used in the calculation of design loading for sites 1 and 2 respectively. The research sites were designed for 10 years design life to withstand traffic loading in the range of 1 to 2 msa. The structural pavement design utilizes the Empirical design method adopted from Malaysia's Manual on Pavement Design [4] which is based on AASHTO 1983 design method. **Table 1** summarizes the pavement design for each of the respective sites and sections.

Table 1 - Study Sections and Respective Treatment

	Site 1: Felda Pekoti Timur	Site 2: Felda Krau
Section	Design Loading = 1 msa	Design Loading = 2 msa
1	(CIPR Cement) CIPR 200mm + Overlay 60mm AC	(CIPR Cement) Top up 100mm C/run* + CIPR 200mm + Overlay 80mm AC
2	(CIPR Foamed Bitumen) CIPR 150mm + Overlay 60mm AC	(CIPR Foamed Bitumen) Top up 100mm C/run* + CIPR 200mm + Overlay 80mm AC
3	(CIPR Lime) CIPR 200mm + Overlay 60mm AC	(CIPR Emulsion) Top up 100mm C/run* + CIPR 200mm + Overlay 80mm AC
4	(CIPR Emulsion) CIPR 150mm + Overlay 60mm AC	(CIPR Lime) Top up 100mm C/run* + CIPR 200mm + Overlay 80mm AC
5	(Control Section) Top up 100mm Crusher run + Overlay 60mm AC	(Control Section) Top up 150mm Crusher run + Overlay 80mm AC

2.4 Field Testing

The field test program involved two (2) phases namely Phase I (pre-construction) for identification of existing condition and rehabilitation design; and Phase II (post-construction) for monitoring of performance and environmental influences during the 5-year study period. **Table 2** summarizes the field test/survey carried out at each study site.

Table 2 - Schedule of Field Test/Survey

Test/Survey	Spacing	Time Interval (Month)**	Parameters Obtained
Manual Surface Condition Survey	10 meter-block	1,6,12,24,36,48, 60	Crack, rutting, other surface defects
Asphalt Coring & DCP	75 meter (6 no/section)	0(DCP only),1	Layer thicknesses
Falling Weight Deflectometer (FWD) Test	50 meter	1,6,12,24,36,48,60	Deflection, modulus, residual life
Traffic & Axle Load Survey	-	0	Traffic volume, Loading
Walking Profiler	10 meter	1,6,12,24,36,48,60	International Roughness Index (IRI)

** Month 0 denotes pre-construction

2.5 Laboratory Tests

Pre-construction laboratory tests were carried out to determine the engineering properties of the existing materials, their quality and suitability for recycling. The outputs were also used for mix design purposes. The tests included determination of Atterberg Limits, aggregate gradation, Unconfined Compressive Strength (UCS) and Indirect Tensile Strength (ITS). The UCS and ITS (soaked and unsoaked) tests were carried out to determine the amount of stabilizers required to achieve the minimum strength. The UCS test is done on the samples prepared with a range of stabilizer contents and cured for 7 days, and tested in compression in accordance with test 11, BS 1924 or BS 1881: Part 116 [5]. For the ITS test, a standard Marshall Compaction technique of 75 blows per side is carried out (ASTM D1559) and samples are cured for 72 hours at 40^{o} C.

Samples taken from site during construction were tested in laboratory to determine the strength parameters of the recycled layer material. The tests included Indirect Tensile Strength Test (ITS), Unconfined Compressive Strength Test (UCS) and Indirect Tensile Stiffness Modulus.

2.6 Construction Methodology

The area was thoroughly investigated and checked for the presence of any underground utilities especially cabling work to avoid being damaged during the recycling work. The percentages of stabilizing agents and/or water contents were first determined during the mix design stage at the laboratory. The required quantity of Ordinary Portland Cement (OPC) or lime was spread manually over the identified recycling sections. The area was then recycled using a recycling machine to a depth ranging from 150mm to 200mm depending on the pavement structural design. Figure 3 depicted the recycling machine used at one of the site.

Figure 3 - Recycling machine

Figure 4 - Vibratory roller

Immediately after break-down compaction using a smooth drum roller, a grader was used to re-profile the finished recycled layer. Further compaction by vibratory roller (**Figure 4**) was carried out to achieve the required degree of compaction. The recycled materials that have been stabilized needs to be properly cured to achieve the minimum strengths prior to opening to traffic.

The surface to receive the asphaltic concrete layer was to be cleaned, free from loose materials and standing water. It has been a standard practice in Malaysia, and as required by the specification that the bituminous overlay be carried out 3 days after recycling works is completed. Prior to overlaying of asphaltic concrete wearing course (ACWC), a layer of prime coat was applied and allowed for curing within 24 hours (**Figure 5**). After the specified ACWC thickness was laid, the road was not allowed to be trafficked until compaction has been completed and the material cooled thoroughly (**Figure 6**). This cooling down process normally takes about 4 hours from the initial compaction process.

Figure 5 - Prime coating

Figure 6 - Compaction of ACWC

3.0 RESULTS AND ANALYSIS

3.1 Observed Performance after Construction

Construction for the first site was completed in October 2006. Hence, at the time this paper was prepared, data of up to 60 months was made available. However, for the second site construction was completed in December 2007 and therefore only data for post construction monitoring up to 48 months were presented.

The research sites are monitored for their functional and structural performance. The functional performance of the pavements is evaluated using the International Roughness Index (IRI), percentage of cracks and rut depth as shown in **Table 3**. The same criterion was also used to interpret functional condition for roads in Malaysia based on Road Assets Management System. The structural performance is measured in terms of mean FWD central deflection and Resilient Modulus (E-modulus value).

Table 3 - Functional Condition Criteria

Parameter /Condition criteria	Roughness, IRI (m/km)	Rut Depth (mm)	Crack (%)
Good	< 2.0	< 5.0	< 5.0
Fair	2.0– 3.0	5.0 – 10.0	5.0 – 10.0
Poor	> 3.0	> 10.0	> 10.0

3.2 Pavement Functional Performance

Site 1 – Felda Pekoti

The data from **site 1** indicated fair to poor riding quality in the form of International Roughness Index (IRI) with values ranging from 2.8 m/km to 3.3 m/km after rehabilitation. These IRI values gradually increased with varying rate of change. After 60 months, control section recorded the highest IRI value of 5.9 m/km, followed by emulsion, cement, lime and foamed sections. Cracks started to appear on control and emulsion sections after 24 months. For 60 months monitoring, cement section recorded the highest percentage of cracks area of 4.5% (majority C1 crack type), followed by control section with 4.0% area of cracks but majority with C4 crack type. Rutting was considered to be in good condition with cement, foamed, lime and emulsion sections recorded rut depth of less than 5 mm after 60 months. Control section recorded rut depth of 6 mm, considered to be in fair condition after 60 months.

Site 2 – Felda Krau

For **site 2**, IRI values ranging from 2.0 m/km to 4.1 m/km were recorded after recycling. As at 48 months, cement section recorded the highest IRI value of 9.2 m/km. The high IRI values could be due to the existing profile, surface type and initial pavement roughness which are known to have a significant effect on the future roughness level of the pavement [6]. Cracks values were found to be ranging from 0.3 % to 4.3 % after 48 months, and considered to be in good condition. Similarly, rutting was considered to be in good condition with all sections recorded rut depth of less than 5 mm.

In general, the performance of cement and lime stabilized sections were superior than the other sections, with no fatigue cracking at least until 48 months for site 1 and less than 1% of crack recorded thus far for site 2. Figure 7 illustrates the functional performance of each section over 60 months and 48 months period for sites 1 and 2, respectively. Further monitoring is necessary to relate the long-term pavement functional performance to the treatment types.

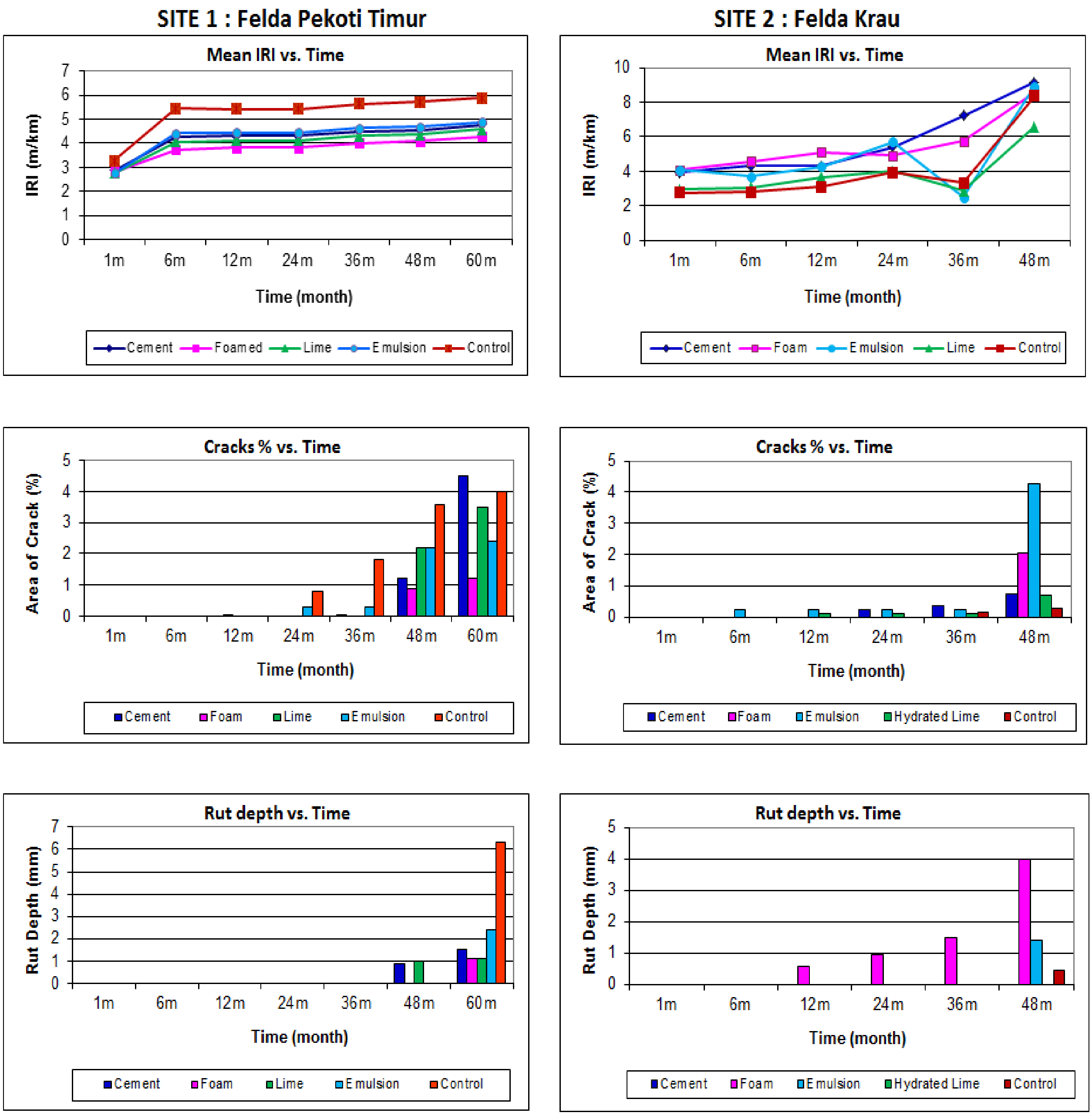

Figure 7 - Pavement Functional Performance

3.3 Pavement Structural Performance

Most of the sections on site 1 were in relatively fair to poor structural condition based on the FWD central deflection data. Control section was observed to record the highest central deflection exceeding 700 microns after 6 months of recycling. On the contrary, emulsion section is the only section relatively in good condition with 388 microns after 60 months. From Elastic Modulus data, cement section was found to record the highest values at 1,187 MPa and the lowest was found to be in control section with 276 MPa.

It was also observed that majority of the sections on site 2 was in relatively fair to poor structural conditions with FWD central deflection values within 400 to 700 microns. Lime section recorded FWD central deflection value of 249 microns after 48 months for it to be in good condition. With respect to the lime and control stabilized layers, high E-modulus values were recorded at both sites.

Based on the construction site records, rainy season experienced during the recycling process at site 2 could have resulted in higher than the optimum/ideal moisture content. As a result, the pavement at 2 sections namely foamed bitumen and emulsion might not gain the required strength and offer a satisfactory interfacing layer for the asphaltic course. With the marginal materials susceptibility to moisture, this could have led to a breakdown of materials, in which under heavy trafficking causes the materials to crack or shoved to the sides as shown in **Figure 8**. Inadequate drainage or poor drainage system might have aggravated failure at both sites.

Figure 8 - Pavement defects

Figure 9 summarizes the structural performance of the 2 sites over 60 and 48 months period, respectively.

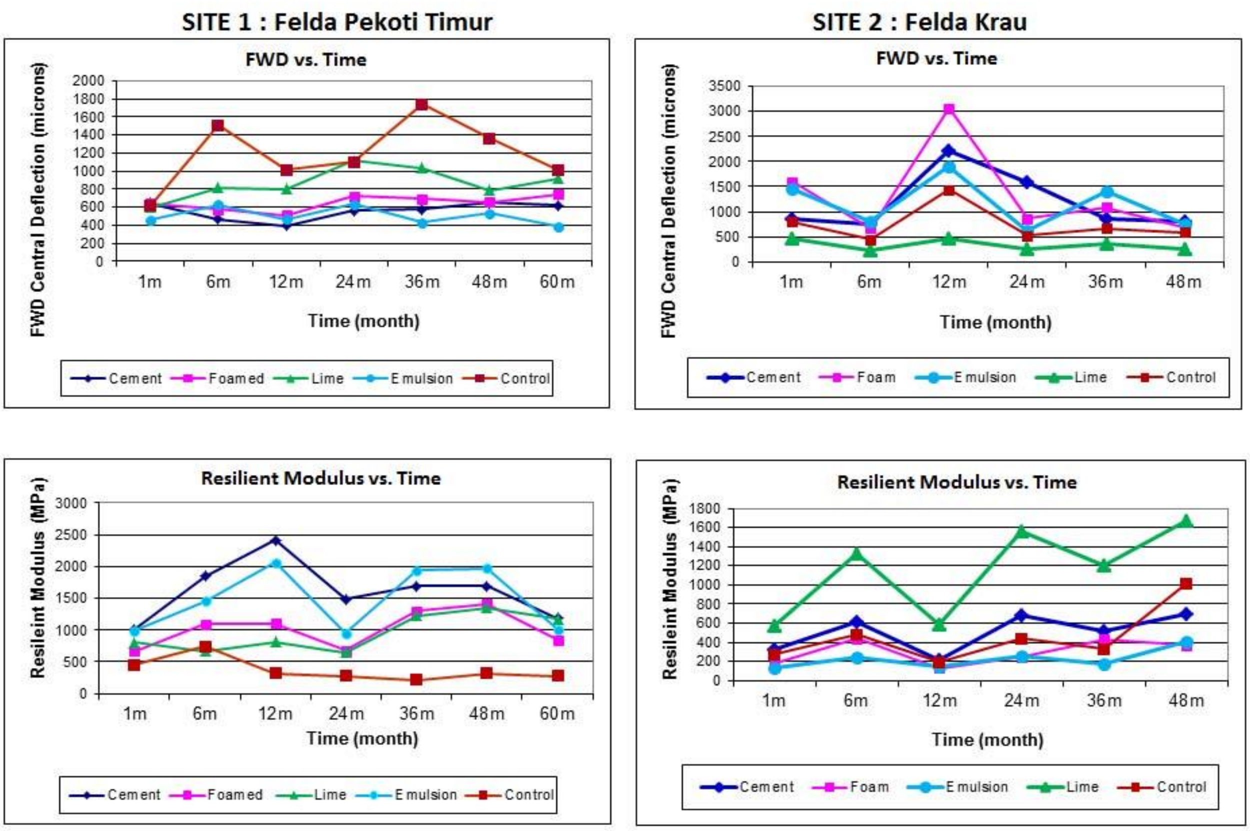

Figure 9 - Pavement Structural Performance

3.4 Laboratory and Field Material Performance

The soil/gravel samples from the two sites were obtained for material laboratory tests as per BS 1377: 1990 [7]. Among the tests include aggregate gradation and determination of Atterberg Limits i.e. Plastic Limit (PL), Liquid Limit (LL) and Plasticity Index (PI). Other tests included determination of moisture content, ITS, UCS and Resilient Modulus test.

3.4.1 Grading and Atterberg Limits

From the sieve analysis, it was found that high clay/silt content of more than 55 percent was observed from site 2 as shown in **Figure 10**. Both samples were also observed to have a PI of 20 as tabulated in **Table 4**. The high PI readings generally indicated clayey soils that are known to be susceptible to moisture and consequently could have affected the performance of sections with high moisture content.

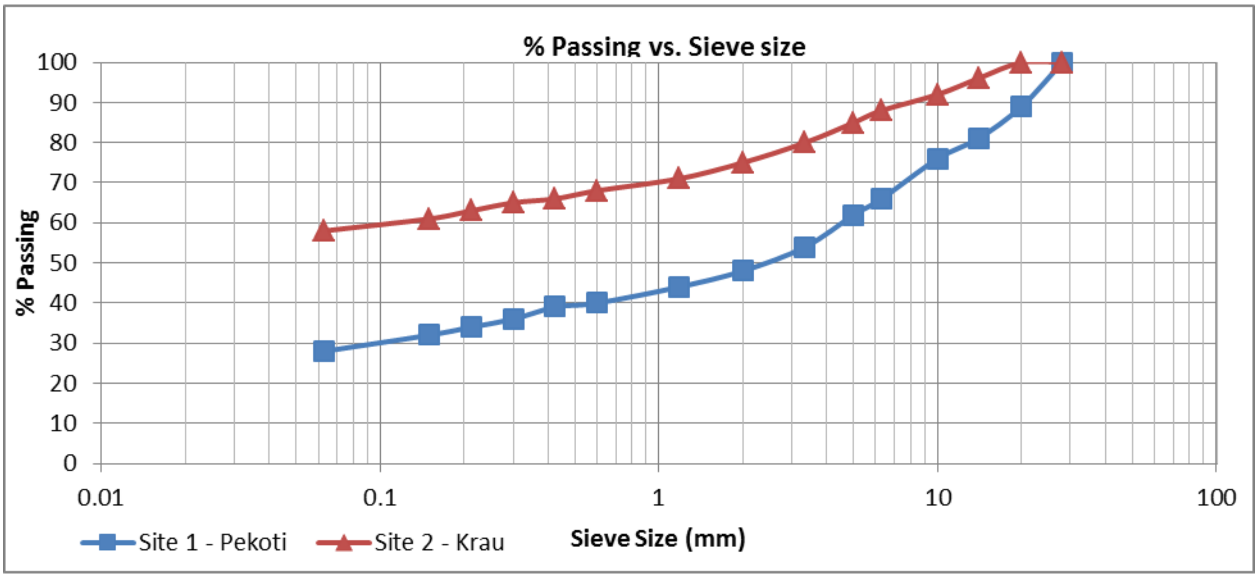

Figure 10 - Aggregate Gradation

Table 4 - Summary of sieve analysis and Atterberg limits results

Site	Atterberg Limits			Sieve Analysis (%)			
	LL	PL	PI	Clay	Silt	Sand	Gravel
1 - Pekoti	42	22	20	28		20	52
2 - Krau	43	23	20	58		17	25

3.4.2 Moisture Content

The field moisture contents as determined by oven method were mostly higher than the Optimum Moisture Content (OMC) of laboratory design mixes. Higher moisture contents had been recorded on field samples either due to poor drainage system and rainy season.

3.4.3 Binder Content

The field binder contents (BC) were calculated by the process of extraction. The field BC for emulsion treated materials was found to be within the tolerance limit with those of the design mixes. However, foamed treated sections recorded lower binder content value as compared to proposed bitumen content. Cement and lime contents of the recycled materials were not evaluated since their amounts were pre-determined and controlled by spreading the required quantities within a specified area.

3.4.4 Bulk density

The field bulk densities, as measured by the proctor test was found to be slightly lower but did not differ significantly from the laboratory bulk densities at OMC for each treatment type. This suggests that slight variation in the aggregate gradation and moisture content has insignificant influence on the bulk density of the materials.

3.4.5 Unconfined compressive strength test (UCS)

The Unconfined Compressive Strength (UCS) values for the field samples were found to be higher than those of the designed mix samples. The UCS values from the field samples at both sites were found to meet the minimum requirement of 2 MPa to 5 MPa for cemented stabilized material and 0.7 MPa for bituminous material. Currently, there is no specified strength requirement for marginal material in terms of UCS value.

3.4.6 Indirect Tensile strength test (ITS)

For emulsion mix at site 2, the field samples recorded low ITS static/soaked value as compared to designed mix samples. The TSR value recorded 39%, which is lower than the allowable limit of 75%. Currently, there is no specified strength requirement for marginal material in terms of ITS value.

3.4.7 Resilient Modulus test

The field modulus value for foamed bitumen and emulsion treated samples at both sites were recorded lower than those of the design mixes. For site 1, it was observed that foamed bitumen stabilized sample produced lower modulus when compared to emulsion stabilized sample after 3 days of curing. However, for site 2, emulsion treated samples produced lower modulus value.

The detailed comparison between the mean test values of designed mix and field samples is shown in **Table 5**.

Table 5 - Comparison between designed mix and field sample

Site /Stabilizer	Measured Parameters															
	OBC/BC (%)		OMC/MC (%)		Bulk Density (g/cm^3)		ITS (kPa)		Soaked ITS (kPa)		TSR (%)		UCS (MPa)		Modulus (MPa)	
	Lab	Field	Lab	Field	Lab	Field	Lab	Field	Lab	Field	Lab	Field	Lab	Field	Lab	Field
Pekoti																
Cement	-	-	5.5	8.4	2.343	2.332	-	-	-	-	-	-	3.7	3.9	-	-
Foamed	3.5	2.2	5.6	9.2	2.428	2.402	582	315	480	234	82.5	74	3.6	5.7	1915	1734
Lime	-	-	5.3	9.3	2.355	2.273	-	-	-	-	-	-	2.3	2.4	-	-
Emulsion	6.0	5.3	5.3	9.6	2.369	2.332	372	350	331	289	89	83	2.0	2.4	6012	4376
Krau																
Cement	-	-	8.5	10.2	2.416	2.209	-	-	-	-	-	-	2.2	2.3	-	-
Foamed	4.0*/2.5**	3.0	8.5	8.6	2.416	2.214	218	238	187	165	85.8	69	1.1	1.3	5233	4233
Lime	-	-	8.5	7.6	2.416	2.057	-	-	-	-	-	-	2.0	2.2	-	-
Emulsion	6.0*/1**	6.6	8.5	6.7	2.416	2.269	269	188	217	73	80.7	39	1.1	0.9	4036	3841

Note: * Optimum binder content (%)
** Cement content (%)

3.5 Cost Analysis

Since the deterioration models for CIPR pavement stabilized with various stabilizing agents have not been established up to this stage, the cost analysis was based on initial construction cost for different treatment types. Difference in cost is due to the different design, which varies in the thicknesses of asphaltic, crushed aggregate and recycled layers, as tabulated in **Table 1**. It was noted from both sites that control section produce the lowest cost, followed by CIPR with cement, lime, foamed bitumen and emulsion as shown in Figure 11. However, from the data collected, it was observed that the premature distress or failure on control, foamed bitumen and emulsion sections were high and this would in turn increase the maintenance cost in the long run.

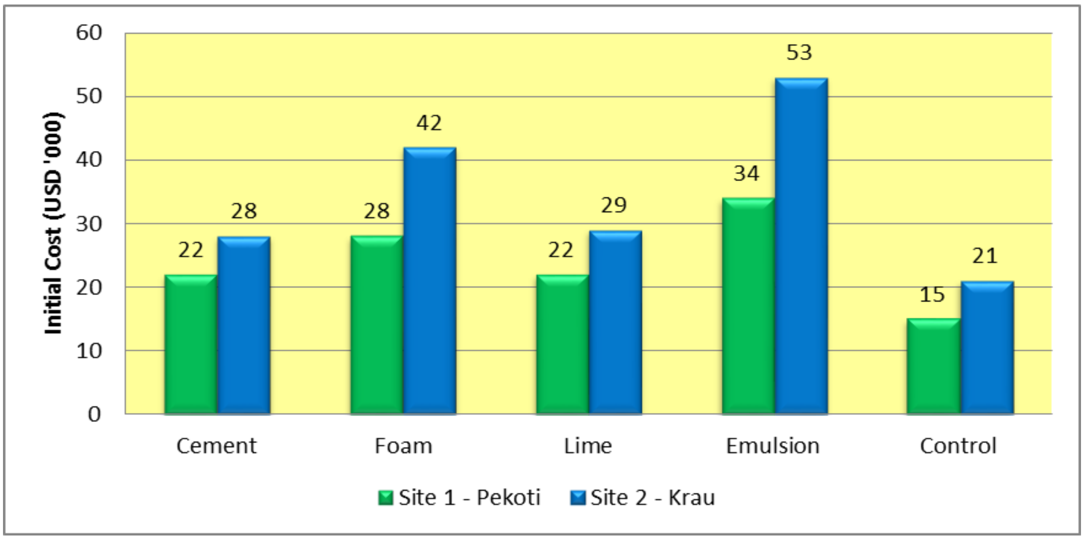

Figure 11 - Initial Construction Cost (1 USD = 3.04 MYR)

4.0 CONCLUSIONS

Based on the findings discussed above, the following conclusions could be drawn:

i. The functional and structural performances of certain CIPR pavements on marginal materials are satisfactory or better than that of the conventionally rehabilitated pavements especially for cement and lime stabilized sections.

ii. Foamed bitumen and emulsion sections turn out to be the weakest CIPR pavements on marginal materials based on functional and structural conditions. More thorough studies are proposed to gain understanding of the impact on the performance of bituminous stabilizers on marginal materials.

iii. The need to conduct standard material laboratory test is crucial to prove the effectiveness of the stabilizing agents/treatment options on a particular soil/gravel type.

iv. The adoption of best construction quality practice is important if optimum performance of the in-situ stabilized marginal material is to be achieved. Controlled curing and monitoring the level of moisture/bitumen contents is vital to ensure the pavement performed satisfactorily.

5.0 FUTURE DIRECTION

It is hoped that the results obtained throughout this research work will provide the road authorities with a clear understanding and reference as to the benefits and limitations of CIPR pavements, particularly recycling on the marginal materials. The findings of this research work would also help in improving the current specification and guideline of CIPR in Malaysia. More thorough studies on application of CIPR on marginal materials should be carried out to substantiate the findings and observation from this research work.

REFERENCES

1. Public Works Department, Malaysia (2009). Road Statistic *2009*.

2. Vic Roads Tech Bulletin 39 – Guide to General Requirements for Unbound Pavement Materials*.*
3. Pavement Recycling Guidelines for Local Governments (1987), FHWA, Washington, DC.
4. Manual on Guidelines of Pavement Design 5/85. Public Works Department, Malaysia
5. BS 1924-2:1990 Stabilized materials for civil engineering purposes. Methods of test for cement-stabilized and lime-stabilized materials
6. K.L. Smith. et.al. (1997). Smoothness Specifications for Pavements. Transportation Research Board, National Research Council.
7. BS 1377-1:1990 Methods of test for soils for civil engineering purposes.