PERFORMANCE OF COLD BITUMINOUS EMULSION MIXTURES (CBEM'S) INCORPORATING WASTE MATERIAL

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ABSTRACT

This paper presents brief design procedure and the performance of Cold Bituminous Emulsion Mixture (CBEM's) incorporating waste material. Three design procedures were combined and adopted in this investigation. One was based on the Asphalt Institute guidelines, two others were based on the AASHTO. The binder used was a Cationic Bitumen Emulsion that contains 62 % residual bitumen of 100-pen grade base bitumen produced by TotalFinaElf Ltd.-UK. The aggregates were limestone coarse aggregate, red porphyry sand a by-product of stone crusher, and limestone filler.

The results indicated that the Optimum Residual Bitumen Content was 6 %. Most properties tested meet the specification. However the Total Voids in medium compaction was 12.575 % that can be reduced by simply increasing the compactive effort to heavy compaction that gave 9.155 % which is within the allowable range.

The strength of the mixture can be significantly increased by either adding or substituting the filler with 2 % Ordinary Portland Cement in order to be equal with hot mixes at full curing condition where all water content had evaporated.

It can be concluded that by increasing compactive effort, the total voids can be reduced. Addition or substitution of filler with OPC gives significant strength improvement. However, the concern remains on weak early strength and long curing time. Therefore a lot of efforts are still need to be endeavored to improve the performance of CBEM's.

Keywords: Cold Mix, Emulsion, and Waste Materials

INTRODUCTION

There has been an increasing concern on environment pollution due to gas emission to the air, that among other comes from the production of Hot Asphalt Mixtures. This is then coupled with issues on energy saving, environment conservation and safety at work had generated interest in Cold Asphalt/Bitumen Mixtures using Bitumen Emulsion or Cold Bituminous Emulsion Mixtures (CBEM's). CBEM's is an asphalt-aggregate mixtures for road pavement using liquid asphalt/bitumen which is an emulsion of asphalt/bitumen in water aided by a suitable emulsifier. As it utilizes liquid binder, CBEM's can be produced at room temperature.

Additionally the CBEM's can also be incorporated with selected waste materials. This technology had been widely accepted in the USA and France since the 1970's. However, due to climatic condition in the UK (where this investigation is being carried out) that is relatively wet / cold and sufficient hot asphalt mixing plant available, cold asphalt mixtures in the UK is being brought forward (Leech D., 1994).

Up to date, there is no 'universally accepted' mix design method for cold bituminous emulsion mixtures. In addition, correlation and assessment of test results are still vary among researchers and institutions, therefore there are *lack of uniform procedures for laboratory evaluations*. In the UK attention on cold mix cold lay materials is encouraged by the issue of ' Specification for Reinstatement of Openings in Highways ' by the Highway Authority and Utility Committee (HAUC) in 1992, which allows the use of Permanent Cold Lay Surfacing Materials (PCSMs) as an alternative to hot mix materials for reinstatement works in low volume roads and footpaths. The PCSMs however should perform adequately after two years of guarantee period which is become a major challenge (Leech D., 1994).

CBEM's has been universally accepted for low to medium traffic conditions, for works in remote areas and for small scale jobs such as reinstatement work. CBEM's are still considered inferior to hot asphalt mixture. There are ***three main concerns*** on CBEM's, namely : ***high porosity*** of the compacted mixture , ***weak early life strength*** (as it contains water) and ***long curing time*** (evaporation of water/volatile content) required to achieve maximum performance. Studied by Chevron Research Company in California, concluded that full curing of cold bituminous mixtures on site may occur between 2 - 24 months depending on weather condition (Leech D., 1994). The mixture is also having some

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other problems such as : binder drainage in storage because of low binder's viscosity, binder stripping due to weak adhesion and poor coating on the coarse aggregates (Leech D., 1994). However these minor problem can be overcome due to the improvement of emulsion technology and cold mix productions. This investigation is still in ***an initial stage of an on going research*** by the author (Thanaya A., 2000).

The main aim of this investigation is to investigate ways of improving CBEM's volumetric and mechanical properties. The physical targets aimed at are to produce mixtures that satisfy the following volumetric and mechanical guidelines:

- Porosity values of compacted mixtures; 6 - 12 % (Nikolaides, 1994), 5 - 10 % (MPW-RI, 1990).
- *Indirect Tensile Stiffness (ITSM) of 2000 - 2500 MPa (HAUC, 1992 & TRL Report 386, 1999).*

EXPERIMENTAL METHOD

Materials Used

The aggregates used were limestone coarse aggregate, red porphyry sand a by-product of stone crusher, and limestone filler. The binder was a Slow Setting Cationic Bitumen Emulsion Produced by TotalFinaElf-UK. This emulsion was produced by processing a Venezuelan 'heavy crude oil'. The main properties of the materials used are presented in Table 1, 2, and 3. The filler was Limestone filler that had been commonly used with SG of 2.765.

Table 1. Properties of Carboniferous Limestone coarse aggregates.

Properties *	Values
Aggregates Abrasion Value	15.5
Aggregates Crushing Value	25
Aggregates Impact Values	21
10 % Fines Value (Dry)	150
10 % Fines Value (Wet)	140
Magnesium Sulfate Soundness Value	94
Polished Stone Value	34
Bulk Density Uncompacted	1357
Bulk Density Compacted	1518
Specific Gravity, Oven Dried (Bulk)	2.63
Specific Gravity, S.S.D	2.65
Specific Gravity, Apparent	2.70
Water Absorption	1.00 %

* in accordance with BS 812 , Part 2 ,1995

Source : Tarmac Northern Ltd . Durham DH3 2ST , Product Data

Table 2. Characteristics of Red Porphyry Sand

Properties *	Values
Bulk Density Uncompacted	1450 g/cm^3
Bulk Density Compacted	1760 g/cm^3
Specific Gravity, Oven Dried (Bulk)	2.54
Specific Gravity, S.S.D	2.59
Specific Gravity, Apparent	2.67
Water Absorption	0.90 %
Chemical Analysis (main constituents):	
- SiO2	71.4 %
- Al2O3	14.4 %
- Fe2O3	1.94 %
- MgO	0.50 %
- CaO	0.31 %
- L.O.I	0.86 %
- pH	8.6

* in accordance with BS 812 , Part 2 ,1995

Source : Tarmac Northern Ltd . Durham DH3 2ST, Product Data

Table 3. Properties of Bitumen Emulsion.

Description	TotalFinaElf Emulsion
Type	Cationic
Base Bitumen	100 pen
Bitumen Content	62 %
SG of Base Bitumen	1.02

Source: Nynas UK AB and TotalFinaElf Bitumen Ltd.

Aggregates Gradations

Materials for use as coarse aggregates were graded into the following fractions: (12.7-10), (10-5), (5-2.36) mm. The fine aggregates, i.e. the red Porphyry sand and the steel slag dust were sieved to obtain the following fractions; (2.36-1.18), (1.18-0.60), (0.60-0.30), (0.30-0.075) mm in order to obtain gradation control. The filler component was classified as material passing (75 microns). To maintain a degree of uniformity and to allow for direct comparisons in terms of mechanical properties, the aggregate gradations of all the bituminous mixtures studied in this investigation were restricted to wearing course (WC) gradations. The gradation was determined using the following modified Fuller's gradation curve proposed by Cooper (Cooper et. al., 1985):

$$P = \frac{(100-F)(d^n - 0.075^n)}{D^n - 0.075^n} + F \qquad (1)$$

where

P = % material passing sieve size d (mm),
D = maximum aggregate size (mm),
F = % filler,
n = an exponential value that dictates the concavity of the gradation line.

The gradations designed in this investigation were also compared with the gradation recommendations by Nikolaides for the same top aggregate size (Nikolaides, 1994) as shown in Fig.1. The choice of 4% filler content and n = 0.45 for all mixtures was designed to keep all the gradation curves within the Nikolaides recommended gradation limits and very close to the lower recommended limit. Additionally n = 0.45 is the exponent used by Superpave Level 1 Mix Design recommendations for best aggregate packing.

Such gradations above has not yet been made available within the specification of The Ministry of Public Works Republic of Indonesia (MPW-RI, 1990).

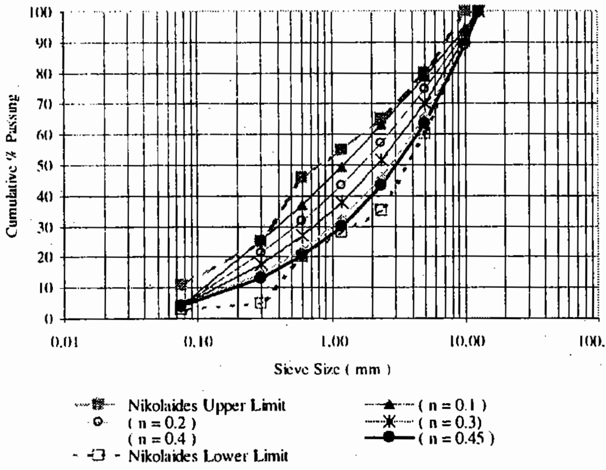

Figure 1. Gradation of the Wearing Course used in this investigation (n = 0.45)

Cold Bituminous Emulsion Mix Design Procedure

The authors of this investigation have studied three CBEM's design procedures; a- Asphalt Institute (U.S.A.) (Asphalt Institute, 1989), b- The Ministry of Public Works Republic of Indonesia (MPW-RI) which is based on AASHTO specifications (MPW-RI, 1990), and c- experimental results supported by full scale trials conducted at Leeds University and Indonesia respectively by Nikolaides et al. (Nikolaides, 1994). In general , the adopted design procedure is basically a combination and mainly follows Modified Marshall Design Procedure and experiences obtained during the course of this investigation. Most part of this design procedure is covered within The Paving Specifications Utilizing Bitumen Emulsions, Ministry of Public Work Republic of Indonesia (MPW-RI) which was referred to by Nikolaides, a consultant who worked in Indonesia in 1990 (Nikolaides, 1994).

Initial Mix Design Procedure adopted.

The Design Procedure below was adopted for designing wearing course mixtures which is as a combination of three design procedure previously mentioned.

Determination of Initial Emulsion Content (IEC)

The first step is to calculate the Initial Residual Bitumen Content (IRBC), designated as P, utilizing the Asphalt Institute empirical formula as shown below (Asphalt Institute, 1989):

$$P = (0.05\,A + 0.1\,B + 0.5\,C) \times (0.7) \qquad (2)$$

where

P = % Initial Residual Bitumen Content by mass of total mixture,
A = % of aggregate retained on sieve 2.36 mm,
B = % of aggregate passing sieve 2.36 mm and retained on 0.075 mm,
C = % of aggregate passing 0.075 mm.

For the gradations of the mixture a value of P = 6 % was obtained. The IEC (Initial Emulsion Content) value can be determined by dividing P by the percentage of bitumen content in the emulsion:

$$IEC = (P / X)\,\% \qquad (3)$$

where

IEC = Initial Emulsion Content by mass of total mixture and
X = the bitumen content of the emulsion.

Coating Test

Using the IEC value from equation (3), the Coating Test was carried out by mixing all of the batches aggregates and filler, and pre-wetted with water. The Bitumen emulsion is added afterwards and then mixed for about 2-3 minutes until even coating obtained. Excessive mixing can cause stripping of the emulsion from the aggregates surfaces. The Optimum Pre-wetting Water Content (OPWwc) that gave the best bitumen coating on the mineral aggregates (in which the mixture is not too sloppy or too stiff) was thus determined. Whilst keeping the IEC content constant, the added pre-wetting water was varied in increments / decrements of 1%. It was found that the (OPWwc) was equal to 5 %, which is equivalent to 8.38 % Total Liquid Content (TLC). TLC is defined as the percentage of (pre-wetting water + emulsion) by mass of total mixture. The degree of coating should be not less than 75 % by visual observation (MPW-RI, 1990).

Determination of Optimum Total Liquid Content at Compaction (OTLC)

The compaction was carried out using Gyropac Compactor ,that can give kneading motion to simulate field compaction. Initial compaction trials had indicated that using Medium Gyratory Compaction effort (Gyropac set at 80 revolutions, 240 kPa axial pressure) produced compacted cold bituminous specimens containing high Porosity values (12.575 %). Therefore the OTLC was determined based on the IEC using Heavy Compaction (Gyropac set at 120 revolutions, 240 kPa axial pressure) , and 2° angle of gyration for 100 mm diameter samples.

The first batch of samples was produced and compacted at 1% above the OPWwc, whilst the second batch was prepared and compacted at OPWwc. The third, the fourth and the fifth batches of specimens was also prepared at OPWwc, but was then air dried using a Hair Drier until 1%, 2 % and 3 % respectively of the water content was evaporated before commencing compaction. The Hair Drier used gave a constant supply of warm air at 38°C. Graph of Dry Density/SG vs TLC at compaction was plotted. For the mixtures investigated, the OTLC was found to be at 5 % OPWwc or at 8.38 % TLC which gave the highest Dry Bulk Density/SG values of the compacted specimens, i.e. 2.154 on Heavy Compaction (Figure 2c) that gave 9.155 % Porosity (Figure 2.d).

Excess of water during compaction should be taken care properly by absorbing it with paper towels.

Variation of Residual Bitumen Content (RBC)

Whilst maintaining a constant OTLC value, the RBC was varied at two points above and two points below the 6 % initial RBC in steps of 0.50 %. Specimens were mixed, compacted and tested at each of these RBC values.

Curing

Two curing procedures were adopted in this investigation. The first procedure (referred to as "design curing") was used to assist in determination of the mechanical and volumetric properties during the mixture design procedure (i.e. to assess the influence of variations in PWwc and TLC values). On the other hand, the second procedure (full curing) was carried out on the final mixtures to determine their maximum mechanical properties.

Design Curing for mix design purposes, when determining Optimum Residual Bitumen Content was carried out in two stages:

Design Curing Stage A; Oven Curing Compacted Samples for Dry Stability Test: This conditioning procedure consisted of keeping the samples for 1 day in their moulds after compaction. The samples were then extruded and kept for 1 day in an oven at 40°C, they were then removed from the oven and stored for 1 day at room temperature (24°C). Some of the samples were subsequently tested for Marshall Stability at room temperature and the results obtained were referred to as (*Dry Stability*).

Design Curing Stage B; Water Conditioning (capillary soaking) Samples for Soaked Stability Test : After having been subjected to Oven Curing as explained earlier, the remainder of the untested Dry Samples were water conditioned (capillary soaking). In this procedure half the thickness of each compacted specimen was soaked in water at room temperature for 24 h, the specimen was then inverted and the other half was soaked for a further 24 h. During soaking, the samples would rest on a bed of approximately 15 to 20 mm coarse sand. The samples were subsequently towel dried then tested for Water Absorption and Marshall Stability at room temperature and the Marshall Stability test results obtained were referred to *as Soaked Stability* values. At this condition the samples have not yet achieved full curing , i.e. still contain water about 0.5 % to 1 %.

'Full Curing' Procedure for the determination of ultimate Mixture Properties:

In this procedure the specimens were left in their compaction moulds for 1 day at room temperature, followed by x days in an oven at 40°C (until a constant mass was achieved) . At this condition the all water content within the samples should have been evaporated (full curing condition). Finally the samples were left to cool down to room temperature (24°C) for 1 day. At the end of this curing procedure the specimens were tested for Indirect Tensile Stiffness Modulus (ITSM) at 20°C using Materials Testing Apparatus (MATTA). A typical time

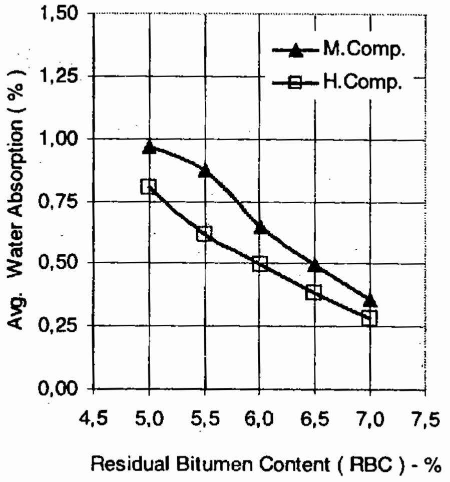

Fig. 2.e Water Abs. vs. RBC

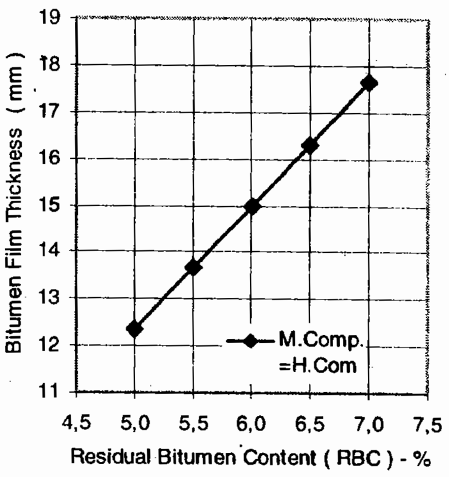

Fig. 2.f BFT SG vs. RBC

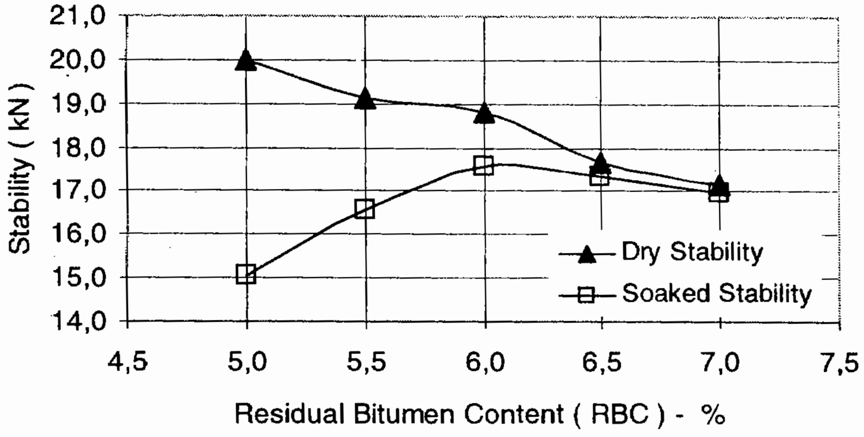

Fig. 3 Stability vs. RBC (Heavy Compaction)

Some useful formulas for determining the properties of the CBEM's is given below :

- $SGmix = \dfrac{100}{\dfrac{\%CA}{SGCA}+\dfrac{\%FA}{SGFA}+\dfrac{\%F}{SGF}+\dfrac{\%Binder}{SGBinder}}$, by weight of total mix
- $Porosity(P-\%) = \left(1-\dfrac{BulkDensity}{SGmix}\right)\times 100\%$
- $BulkDensity/SG = \left(\dfrac{Weight.in.air}{(Weight.in.air - Weight.in.water)}\right), gr/cm3$
- The Bitumen Film Thickness (BFT) is calculated using formula (Witheoak D., 1991, pp.332) :

$$BFT = \frac{\%.Binder}{100-\%.Binder}\times\frac{1}{SG.Binder}\times\frac{1}{ASA}$$

where

ASA = aggregate surface area was determine with reference to Hveem Method of Mix Design (Asphalt Institute , 1995)

The properties of the samples at ORBC on Design Curing Condition is presented in Table 5.

CBEM's incorporated 2 % added Cement (OPC), and 2 % substituted Cement (OPC)

In order to improved the strength of the CBEM's. Ordinary Portland Cement (OPC) was incorporated in the amount of 2 % by weight of total aggregates. Other samples were manufactured, in which 2 % out of 4 % limestone filler was substituted with cement. The results is given in Table 6.

Production of Hot Mixes with similar materials and gradation with the CBEM's –Control Hot Mix (CHM).

For comparison purposes , control hot mixes (CHM) samples were also produced using the same base bitumen (100 pen bitumen), with results as shown in Table 7.

RESULTS

Summary Results of the investigation are presented in Table 4, Table 5, Table 6, and Table 7.

Table 4. Results of Coating Test and Optimum Residual Bitumen Content (ORBC).

Mixture	IEC (%)	Variation of added water (%) by wda*	Added water for best coating (%) by wda*	Estimated degree of coating (%)	ORBC (%)
CBEM's, using Total's Emulsion	6	4 , 5 , 6 , 7	5 which equals to 8.38 TLC **	± 90 ***	6

* wda ; weight of dry aggregates ** TLC : Total Liquid Content

*** Requirement of Degree of coating > 75 %, by visual observation (MPW-RI, 1990).

Table 5. CBEM's Properties at Optimum Residual Bitumen Content (ORBC) on Design Curing Condition at room temperature 24 °C, and Specifications.

No	Description	Characteristics of CBEM's (Average values)					
		Soaked Stability (kN)	Retained Stability (%)	Dry Bulk SG	Total Voids (%)	Water Absorption (%)	BFT (µm)
A	**CBEM's using TotalFinaElf Emulsion:**						
	• Medium Compaction Opt. RBC = 6 % (soaked sample)	15.125	92.137	2.073	12.575	0.647	14.98
	• Heavy Compaction Opt. RBC = 6 % (soaked sample)	17.556	90.676	2.155	9.155	0.494	14.98
	• Ratio of H Comp./Medium Comp.	1.16	0.98	1.04	0.73	0.76	-
B	**Summary of Specifications :**						
1	The Asphalt Institute ,at 22 deg. C	2.225	50 (min)	-	-	-	-
2	Nikolaides, at room temp.	1.335	50 (min)	-	6 – 12	4 (max)	6 (min)
3	The MPW-RI, 1990 , at room temp.	3	50 (min)	-	5 - 10	4 (max)	8 (min)
4	Compactor : Marshall Hammer	2x50 Marshall Blows (Medium Comp)					

Table 6. Summary of Indirect Tensile Stiffness Modulus (ITSM) of the CBEM's - Mega Pascal (MPa), using Heavy Compaction Effort.

No	Mix Type	ITSM (MPa)	Note
1	CBEM's-DC	543.31	DC = Design Curing
2	CBEM's-FC	1142.50	FC = Full Curing
3	CBEM's-FCAC	2506.88	FCAC = Full Curing with 2% Added OPC
4	CBEM's-FCSC	2290.30	FCSC = Full Curing with 2% out of 4 % limestone filler Substitute with OPC

Table 7. Control Hot Mix (CHM), with Heavy Compaction Effort (Gyropac , 120 rev., 240kPa)

Mix Type	Porosity	ITSM
CHM	4.56 %	1771.83 MPa

DISCUSSION

As can be seen on Table 5 and Fig. 2d , at Medium Compaction the Total Voids still higher than the specification, i.e. 12.575 %, meanwhile other parameters adequately meet the Specifications. This can be overcomed by increasing compactive effort that can reduce the Total Voids from 12.575 % to 9. 155 % which falls within the specifications but still too close to the max limit 10 % (MPW-RI, 1990).

Meanwhile, the strength of the mixture at Design Curing Procedure in term of Marshall Soaked Stability, well above the requirement. Therefore the more concern is in term of Total Voids or Porosity of the mixture. This is also confirmed by study results carried out at Liverpool University – UK by Khalid and Eta (Khalid H.A. & Eta K.E. , 1996). They compacted Dense Emulsified Bitumen Macadams using Marshall Hammer with 50 blows (medium compaction) and 75 blows (heavy compaction) per side of the samples. It was obtained that the porosity were 18.73 % and 16.31 % respectively. It can therefore be said that CBEM's require heavier compaction effort to meet porosity target. This is due to the inherent resistance on compaction of the loose mix. The bitumen emulsion appear to quickly absorbs the fine particles and have partly set during mixing, and air drying that causes the loose mixture to some extent had stiffen or harden, hence require heavier compaction.

At full curing condition, as shown in Table 6, the CBEM's-FC is still weaker than its Control Hot Mix (CHM) in Table 7. This is likely because the hot mix can achieve lower Total Voids at the same Heavy Compaction effort (more workable) as compare with CBEM's - FC. The Cold Mix appears to be stiffer after mixing and air drying before compaction. The CHM Total Voids at Heavy Compaction was 4.56 %, meanwhile the CBEM's gave 9.155 %.

In term of Stiffness, with 2 % added cement (CBEM's-FCAC) as well as with 2 % filler substitution with cement (CBEM's-FCSC) give stiffness more than twice the stiffness of CBEM's-FC as shown in Table 6 , and well meet the stiffness target aimed at, i.e. 2000 – 2500 MPa (HAUC, 1992 & TRL Report 386, 1999).

CONCLUSION

It can be concluded that by increasing compaction effort from Medium to Heavy Compaction , the total voids can be reduced to meet porosity target. However heavier compaction level may still very much needed in order to obtain a safer porosity. Addition or substitution of filler with 2 % OPC into the CBEM's gives significant strength improvement that meet target of Stiffness.

The design procedure is still felt less simple. Particularly in the determination of Optimum Total Liquid Content (OTLC) for compaction. This may not practicable or difficult to be applied on site. A different design approach is being investigated by the author.

Further efforts are still needed to be done in order to accelerate the improvement of weak early life strength of CBEM's and to shorten the long curing period required , and more alternatives waste materials need to be tried in support to the conservation of environment.

SUGGESTION

For the acceleration of curing time and to minimize failure of the compacted CBEM's on site , it is suggested that application or construction of CBEM's to be carried out during dry season or summer.

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