ESTIMATION OF PENETRATION REQUIREMENTS FOR PRIME COAT

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Degree of Master of Engineering

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University of Moratuwa
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Thesis submitted in partial fulfilment of the requirements for the degree
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DECLARATION

I declare that this is my own work and this thesis does not incorporate without acknowledgement any material previously submitted for a degree or diploma in any other university or institute of higher learning and to the best of my knowledge and belief it does not contain any material previously published or written by another person except where the acknowledgement is made in the text.

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ABSTRACT

Prime coat application is a necessary activity in road constructions. The main function of the prime coat is to seal capillary voids in the base course surface to prevent migration of moisture to the base course and underneath layers. However it is not carried out up to the required standards. The prime penetration into the road base is the most important consideration. In the local context, the application of prime coat has been a common practice in road construction projects though there is no specification for penetration requirements. This is an issue of concern as there should be a basis for selecting the best type of prime coat in terms of the penetration and penetration requirement for respective type of processed bitumen as well. Commonly used types of processed bitumen for prime application in Sri Lanka are MC-30 (Medium Curing cut back bitumen) and CSS-1 (Cationic Slow Setting). The experimental research was done using both types of bitumen and the Aggregate Base Course (ABC) specified in the Standard Specifications for Construction and Maintenance of Roads and Bridges [2nd Edition – June 2009] specification as the road base. Specimens were casted in AASHTO specified CBR moulds at selected degree of compaction and was sprayed at selected rates under typical defined Sri Lankan conditions. Penetration requirement and required curing time were selected for each degree of compaction and rate of application, and then the penetration requirements for respective required curing time were plotted against the base compaction and rate of application. There is no significant difference of required penetration for both type of bitumen but MC-30 has shown a relatively higher penetration for few time intervals to make it arguably the best to select in terms of the penetration into the base among the two types of bitumen tested. The penetration requirements for MC-30 and CSS-1 with the time are presented and can be used to make decisions on the best type of bitumen to use in terms of penetration and required penetration for a selected type of bitumen with curing time.

DEDICATION

This thesis is dedicated

To

My wife and parents for their support and encouragement

ACKNOWLEDGEMENT

I would like to acknowledge many people who supported me to complete the master's research successfully. First of all I would like to thank my project supervisor Dr. H.R. Pasindu who instructed and guided me to make this a success and gave me the opportunity to explore many areas through guidance and his helpful information to complete the research.

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Thank goes to Oru Mix Asphalt (Pvt) Ltd and Bitumix (Pvt) Ltd for providing materials and Research and Development division of Road Development Authority (RDA) for testing bitumen.

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LIST OF ABBREVIATIONS

Abbreviation	Description
AASHTO	American Association of State Highway and Transportation Officials
ABC	Aggregate Base Course
AEP	Asphalt Emulsion Prime
AIV	Aggregate Impact Value
ASTM	American Society for Testing and Materials
CBR	California Bearing Ratio
CIDA	Construction Industry Development Authority
CSS	Cationic Slow Setting
EPA	Environmental Protection Agency
HMA	Hot Mix Asphalt
ICTAD	The Institution of Construction Training & Development
IMC	Initial Moisture Content
MC	Medium Curing
MDD	Maximum Dry Density
OMC	Optimum Moisture Content
RDA	Road Development Authority
SS	Slow Setting
VOC	Volatile Organic Compound

1. INTRODUCTION

1.1 Problem Statement and Background

Sri Lankan government continues to allocate high proportion of its budgetary allocations for capital expenditure on the road sector. This is with the aim of providing necessary infrastructure for economic growth and enhancing the quality of life of people.

Investments will be effective only if the infrastructures can continue to yield benefits during its life time. So the quality aspects of road construction projects have become more important than ever before.

Prime coat application is a very important road construction activity and a mandatory requirement prior to bituminous surfacing. The main purpose of applying prime coat is to seal the base course hence to prevent moisture infiltration into the underneath layers. Therefore the prime penetration into the road base is the most important factor. Currently a detailed penetration requirements have not been mentioned in the Standard Specifications for Construction and Maintenance of Roads and Bridges [2nd Edition – June 2009] published by Construction Industry Development Authority (CIDA, formerly known as ICTAD) though the recommended application rate is mentioned there. So the problem is that penetration requirements for recommended range have not been given in the ICTAD specification. Therefore this study focuses on finding penetration requirement for recommended application rate range given in ICTAD specification.

1.2 Objectives of the Study

Objectives of this study are to identify penetration requirements and required curing time for recommended application rate in the Standard Specifications for Construction and Maintenance of Roads and Bridges [2nd Edition – June 2009] published by Construction Industry Development Authority.

1.3 Scope of Work

The laboratory experiments were done for prime coat types of MC 30 (Medium curing cutback bitumen) and CSS1 (Cationic Slow Setting Type 1) while the

Aggregate Base Course (ABC) as the road base. Also experiments were done for flat road base so the cross falls of base course was not considered for the study. Experiments were conducted at atmospheric temperatures (25 ^{o}C - 35 ^{o}C) with no rain. The study doesn't cover prime surfaces allowed for traffic during the recommended curing period.

2. LITERATURE REVIEW

2.1 Pavement Structure

A pavement structure typically consists with road base, sub base, sub grade and a wearing course/ surface treatment.

Figure 1 shows a typical pavement structure for flexible pavement

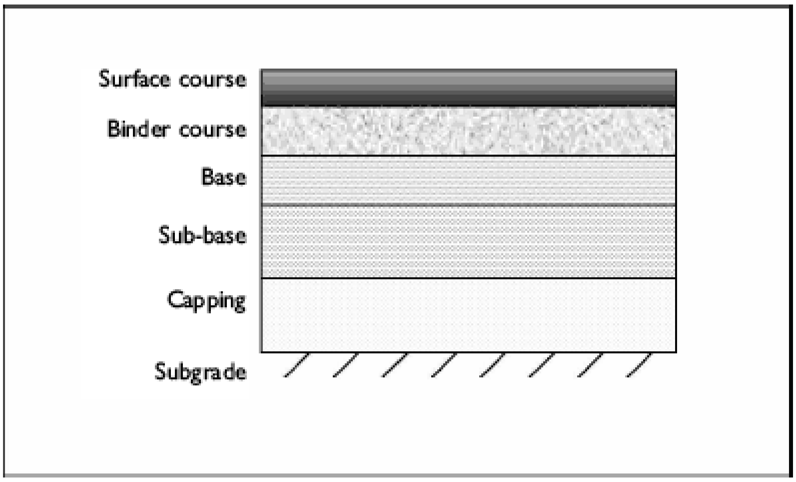

Figure 1: A Typical Pavement Structure for flexible pavement

Source: (Road Assets, 2009)

2.2 Introduction to prime coat

Prime coat materials mainly consist of cutback asphalt, emulsified asphalt or polymer based chemicals.

• Cutback asphalt is manufactured by blending asphalt cement with petroleum solvent

• Emulsified asphalt consists of a suspension of asphalt cement in water

• In Texas the most commonly used prime coat materials are MC-30, AEP, EC-30, CSS-1H and SS-1H

(Yildirim, 2011)

The most utilized and successful prime materials have traditionally been cutback asphalts, but some newer emulsified asphalt specialty primes have been successfully used. Mixing grade emulsified asphalts can be used for priming; however, they must be mechanically mixed into the base as they do not adequately penetrate into a most compacted base. If the primed surface must carry significant traffic or carry traffic for an extended period, then a thin surface treatment, sometimes called an inverted prime or covered prime, typically using cutback asphalt to promote penetration into the base may be in order (Freeman, Button, & Estakhri, 2010, p. 6).

The binder shall be from a source approved and shall consist of medium curing cutback bitumen (25% to 45% cutback) MC -30, MC -70 or MC -250 or cationic bitumen emulsion of grade CSS -1 or CSS -1H (ICTAD, 2009, p. 97)

The indicative rate of spread of cut back bitumen or emulsion for the prime coat shall be in the range of 0.5 to 1.5 l/m^2. (ICTAD, 2009, p. 97)

Medium curing cut back bitumen shall conform to ASTM D2027 Standard Specification for Cutback Asphalt (Medium-Curing Type) and Cationic bitumen emulsion shall conform to ASTM D2397-98 Standard Specification for Cationic Emulsified Asphalt (ICTAD, 2009, p. 463)

Traffic shall not be permitted on the primed surface for a period of 2h or longer until the binder has penetrated and dried up and in the opinion of the Engineer will not be picked up by the traffic (2h was an error and later corrected). However where the engineer deems it impracticable to detour traffic, the Contractor shall spread a sufficient quantity of blotting material in order to prevent the prime coat from being picked up, Prior to allowing the traffic to pass. Any areas which are in excess of or deficient in priming material shall be corrected by the addition of blotting material or binder, as appropriate, such corrections shall be incidental to the work. (ICTAD, 2009, p. 117)

2.3 Introduction to Aggregate Base Course (ABC)

The aggregate shall be graded crushed rock of nominal size 37.5 mm or 28 mm 20 mm.

The aggregate shall be derived from a parent rock that is hard, sound, durable and un-weathered. It shall consist of hard durable particles of fragmented rock from a quarry approved by the Engineer, and shall be free of dust, organic matter, clay and silt or any other deleterious matter. (ICTAD, 2009, p. 97)

Requirements of ABC are shown below

- The Aggregate Impact Value (AIV) determined as specified in BS-812 shall not be more than 30%.
- The flakiness index of the coarse aggregate when determined by the sieve method described in BS-812 shall not exceed 35%.
- The crushed stone shall preferably be non-plastic, but in no case shall the PI exceed 6%.
- The minimum soaked CBR value of material in the base course shall not be less than 80% at the specified in-situ density.

(ICTAD, 2009, pp. 457,458)

2.4 Uses of prime coat

There are various uses of prime coat. Main use of prime coat is to reduce moisture infiltration into the base. In addition to that Prime coat promotes adhesion between base and seal. It also limits absorption of first binder into the base and help to bind fine particles in upper zone together. Limited construction traffic can be allowed on a primed surface as well.
(Kotze, van der Schyff, & van Zyl, 2010)

2.5 Important factors related to prime coat

The major purpose of prime coat is to protect the underlying layers from wet weather by providing a temporary waterproofing layer. Additional benefits of prime coat are stabilizing or binding the surface fines together and promoting bond to the HMA layer. Prime must adequately penetrate the base to function properly.

Medium cure cutbacks are normally used for prime. Medium cure cutback asphalts penetrate deeper than conventional emulsified asphalts. Dilution of emulsified asphalts with water helps penetration, but emulsified asphalts generally require mixing into the base to function properly. Prime coats must be allowed to cure completely before covering with HMA Cutbacks generally takes longer to cure than asphalt emulsions.

Excess prime that is not absorbed into the base after 24 hours should be absorbed with blotter sand and removed from the surface. Prime is often deleted in cold weather because it is riskier to pave over uncured prime than over unprimed base (NCHRP, 1978).

Prime coats are often deleted if no wet weather is anticipated and the base can be covered within seven days. Prime may not be necessary if the HMA is greater than 4 inches thick. Prime coat increased the bond strength at the interface between a compacted base and asphalt layer over that of no prime coat. The reported differences were not always statistically significant. At higher static normal stresses, shear strength at the interface is not appreciably affected by the type or even the presence of a prime coat. This supports the practice of deleting prime at a minimum HMA thickness, typically 4 inches (100 mm).

Use of prime coat is not a substitute for maintaining the specified condition of the base or subgrade. Prime should not be applied to stabilized bases or subgrade. The main environmental concern with prime coat applications is air pollution associated with the release of volatile organic compounds (VOC) into the air. The Environmental Protection Agency (EPA) treats spills of cutbacks and emulsified asphalts the same; therefore, priming with emulsified asphalts or specially formulated penetrating asphalt emulsions does not result in reduced oil spill reporting regulations or requirements. Deleting prime would lessen the amount of liquid asphalt contractors must handle, lessening the associated liability with handling these products. Prime may be omitted if there is a strong possibility of runoff entering a waterway.

(Freeman, Button, & Estakhri, 2010)

3. METHODOLOGY

3.1 MATERIAL SELECTION

3.1.1 MC -30

Medium curing cut back bitumen (MC-30) was purchased from Bitumix (Pvt) Ltd a bitumen dealer and got tested by Research and Development division of Road Development Authority (RDA) to find whether MC -30 conforms to the requirements. Results are shown below.

Table 1: MC -30 Test results

Property	Test Method	Test Results	Specification Limits	
			Min	Max
Kinematic Viscosity at 140 ^{o}F (60 ^{o}C)	ASTM D2170-92	**39**	30	60
Flash Point (Tag open cap) ^{o}C	ASTM D3142-83	**51**	38	--
Specific Gravity at 15.6/15.6 ^{o}C	ASTM D402-76	**0.911**	--	--
Distillation Test Distillate, volume percent of total Distillate to 680 ^{o}F (360 ^{o}C)	ASTM D402-76			
to 437 ^{o}F (225 ^{o}C)		**33**	--	25
to 500 ^{o}F (260 ^{o}C)		**64**	40	70
to 600 ^{o}F (316 ^{o}C)		**83**	75	93
Residue from distillation to 680 ^{o}F (360 ^{o}C), percent volume by difference		**54**	50	--
Tests on residue from distillation test				
Penetration 77^{o}F (25^{o}C) 100g, 5s, mm	ASTM D5-86	**242**	120	250
Ductility 77^{o}F (25^{o}C) 5cm/min, cm	ASTM D113-86	**106**	100	--
Solubility in trichloroethylene %	ASTM D2042-81	**99.2**	99.0	--

3.1.2 CSS-1

Similarly like MC -30, CSS -1 was also purchased from the same bitumen dealer and got tested Research and Development division of Road Development Authority (RDA) to find whether CSS -1 conforms to the requirements. Results are shown below.

Table 2: CSS -1 test results

Property	Test Method	Test Results	Specification Limits	
			Min	Max
Viscosity, Saybolt, Furol at 77 ^{o}F (25 ^{o}C) s	ASTM D244-89	**20**	20	100
Storage stability test, 24hrs %	ASTM D244-89	**0.7**	--	1
Settlement test, 5days %	ASTM D244-89	**0.911**	--	--
Sieve test %	ASTM D244-89	**0.1**	--	0.1
Distillation Test Residue %	ASTM D244-89	**60**	57	--
Tests on residue from distillation test				
Penetration 77^{o}F (25^{o}C) 100g, 5s, mm	ASTM D5-86	**133**	100	250
Ductility 77^{o}F (25^{o}C) 5cm/min, cm	ASTM D113-86	**66**	40	--
Solubility in trichloroethylene %	ASTM D2042-81	**98.9**	97.5	--

Specific Gravity of CSS -1 was checked at the laboratory at approximately 15.56 ^{o}C and found as 1.011.

3.1.3 Aggregate Base Course (ABC)

Aggregate Base Course (ABC) material for the study was taken from a quarry of Oru Mix Asphalt (Pvt) Ltd. situated in Meerigama.

Tests were conducted to check whether ABC conforming to the requirements. Test results are shown below

Table 3: ABC Test results

Property	Test Method	Test Results	Specification Limits	
			Min	Max
Sieve Analysis	BS 1377	(Table 4)	---	---
Aggregate Impact Value (AIV)	BS-812	**24** (Table 5)	0	30
Flakiness Index (FI)	BS-812	**16**	0	35
Plasticity Index (PI)	AASHTO T-90	**Non - Plastic**	0	6
California Bearing Ratio (CBR)	AASHTO T-193	**122%**	80%	---

Note: California Bearing Ratio test was conducted in accordance with AASHTO T-193 without over size correction instead of checking in-situ CBR for ABC.

Table 4: Sieve Analysis Test results

Sieve Size (mm)	Percentage Passing (%)	Specification Limits	
		Min	Max
50.0	**100**	100	100
37.5	**99.1**	95	100
20.0	**69.6**	60	80
10.0	**49.0**	40	60
5.0	**33.1**	25	40
2.36	**18.7**	15	30
0.425	**10.2**	7	19
0.075	**6.6**	5	12

Table 5: AIV Test results

Test No.	**1**	**2**
No. of Blows	15	15
Mass of Dry Aggregate	328.1	328.2
Mass of Dry Aggregate Passing 2.36 mm Sieve	78.4	78.9
Mass of Dry Aggregate Retained 2.36 mm Sieve	249.7	249.3
Aggregates Impact Value (AIV) (%)	23.9	24.0
Aggregate Impact Value (AIV) (%)	**24.0**	

Figure 2: Reduction of sample

Figure 3: Mechanical Sieve shaker

Figure 4: Sieves

Figure 5: Aggregate for AIV test

Figure 7: Performing AIV test

Figure 6: Performing FI test

Table 6: California Bearing Ratio test results - Test method AASHTO - 193

Number of blows	Unit	10 Blows	30 Blows	65 Blows
Dry density	g/cm^3	2.267	2.370	2.485
Corrected CBR	%	110.2	125.4	148.0
Degree of compaction	%	94.9	99.2	104.0

Maximum Dry Density = 2.390 g/cm^3, Optimum Moisture content = 5.85 % (see 4.1.1)

Calculation of water to be added to the sample prior to casting (see 4.1.2)

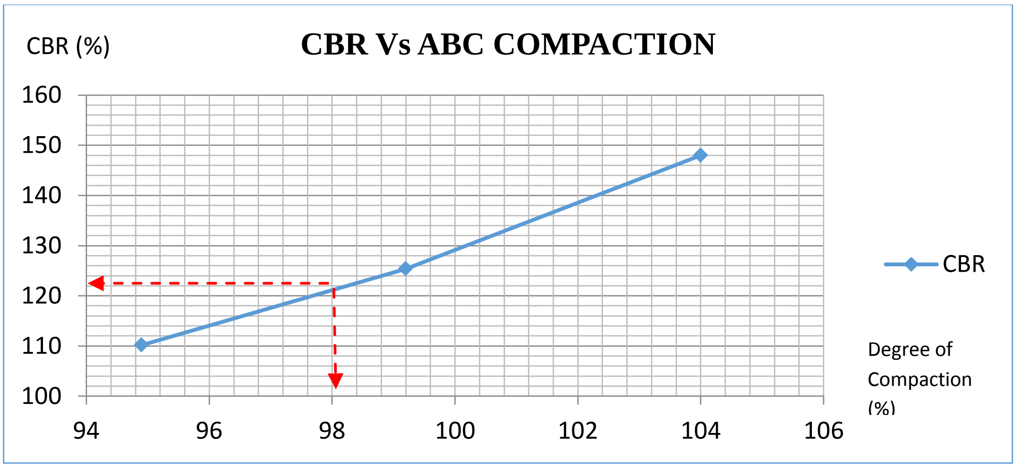

Figure 8: CBR Vs Degree of Compaction relationship

The CBR values of ABC at 98% of MDD = 122 %

After checking the suitability of material, the next step was to achieve the required compactions (95 %, 98 % and 100%) of ABC. Then those specimens were left to dry for 24h period before applying prime. After prime coat application at rates of 0.5 l/m^2, 1 l/m^2 and 1.5 l/m^2 (Application rates were selected to cover the recommended application range of 0.5 l/m^2 - 1.5 l/m^2 in ICTAD specification). After applying prime at selected ranges, primed specimens were left to cure for 30h, and penetration readings were taken at 6h, 12h, 18h, 24h and 30h intervals. Finally results obtained were analysed and concluded.

3.2 Casting ABC specimens

3.2.1 Proctor compaction test

The proctor compaction test was carried out in accordance with the AASHTO T-180 standard to find the Maximum Dry Density (MDD) and Optimum Moisture Content (OMC). The initial sample was dried and reduced by riffling to a sample of approximately 6kg. Five samples of 6kg were taken through reducing process.

Once five number of 6kg samples were prepared. Started with adding 200ml of water into a one sample and mixed thoroughly, then sample was divided into five approximately equal small samples. After that small samples were put into the mould one by one applying 56 blows to each layer. Then weighed the specimen and got a proportion of sample to calculate the moisture content. Similarly the same process was continued to other samples as well but with adding water with 100ml increment (300ml into the second sample, 400ml into the third sample etc...).

Table 7: Proctor Compaction test results

Specimen No.	**1**	**2**	**3**	**4**	**5**
Water (ml)	200	300	400	500	600
Moisture Content (%)	2.5	4.0	5.6	6.9	8.4
Dry density (g/cm^3)	2.242	2.347	2.389	2.372	2.319

Once all the dry densities and moisture contents were calculated. They were plotted on a graph to find out the Maximum Dry Density (MDD) and Optimum Moisture Content (OMC). The graph is shown below.

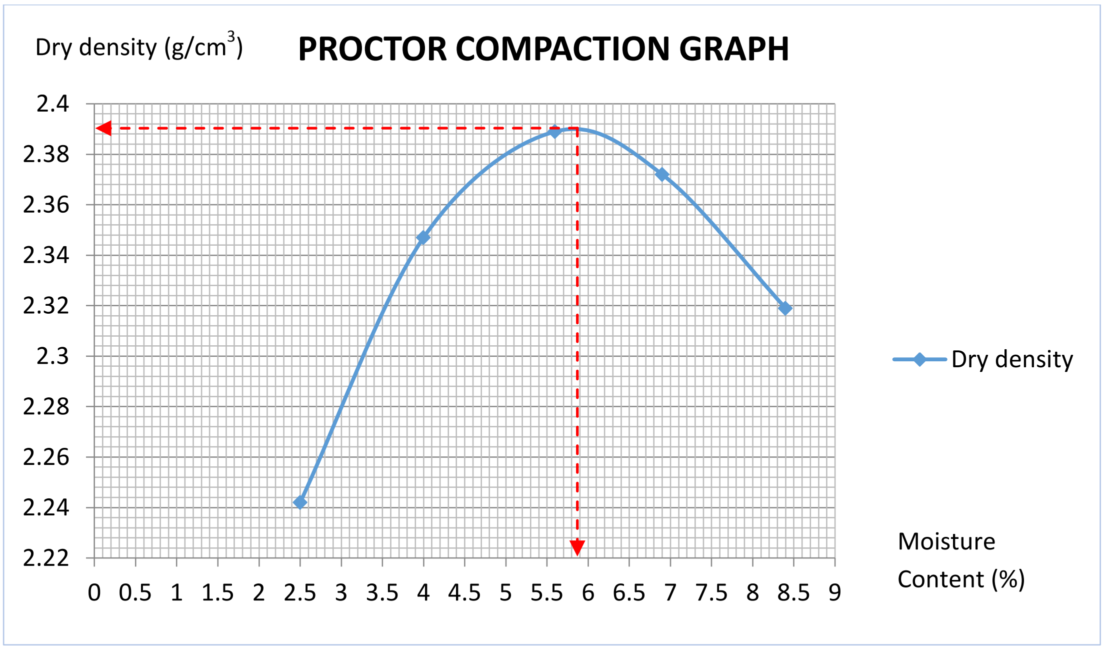

Figure 9: Proctor Compaction graph

<u>According to the graph</u>

Optimum Moisture Content (OMC) = **5.85 %**

Maximum Dry Density = **2.390 g/cm^3**

Figure 10: Weighing sample

Figure 11: Casting ABC specimen

Figure 12: Prepared material, apparatus and casted specimen

3.2.2 Selecting number of blows required to achieve compaction (Trial)

ABC specimens were casted in AASHTO CBR moulds at OMC by applying trial number of blows 10, 20,30,40,50 and 60 respectively to find out the exact number of blows required to obtain 95%, 98% and 100% compaction from MDD. The oversize correction was not done as it changes the grading of ABC, Which could probably affect outcomes of the study in a negative way.

Dimensions of the mould and the rammer are shown below

- AASHTO CBR Moulds (152.4 mm internal dia. x 177.8 mm body height)
- 4.54 kg weight and 457.2 mm height rammer

6kg were reduced from the sample using riffle box and calculated the initial moisture content (IMC) of the sample and then amount of water to be added to the sample was calculated using the following equation.

$$\text{Amount of Water} = \frac{(OMC - IMC)}{100 + IMC} * 6000 \quad ml$$

IMC = 0.8 %

OMC = 5.85 %

$$\text{Amount of Water required} = \frac{(5.85 - 0.80)}{100 + 0.80} * 6000$$

$$= \mathbf{\underline{300.6\ ml}}$$

Then 300.6 ml water was weighed and thoroughly mixed to the sample, specimens were casted with five layers by applying 10, 20, 30, 40, 50 and 60 blows. The following graph shows degree of compactions achieved for each number of blows.

Table 8: Degree of compaction achieved in trial

Number of blows per layer	Degree of compaction achieved (%)
10	92.5
20	96.1
30	98.3
40	99.2
50	100.4
60	101.3

Compactions achieved were plotted on a graph against number of blows.

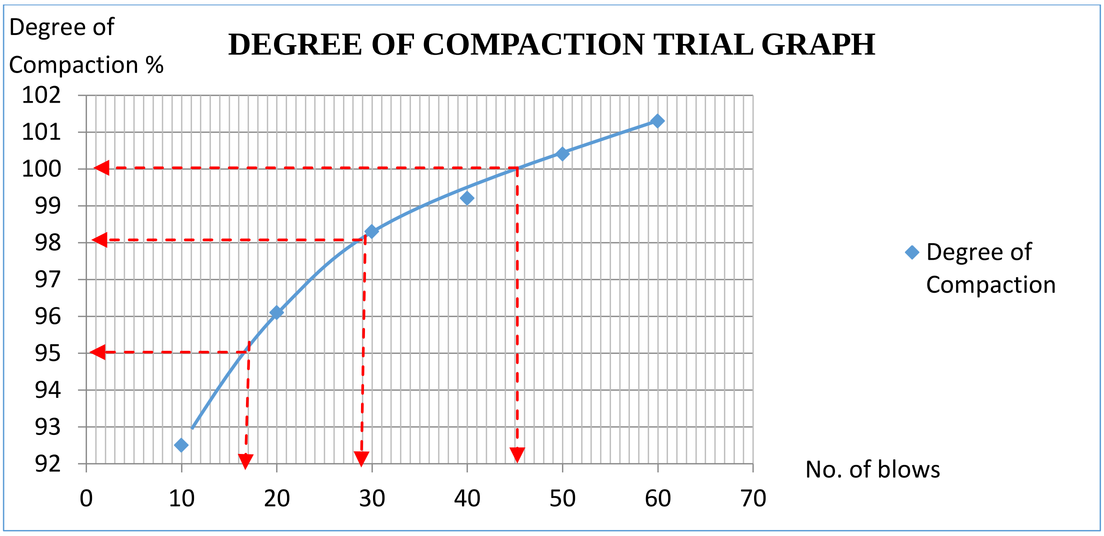

Figure 13: Degree of Compaction achieved in trial

Following number of blows were selected from the graph to achieve the required degree of compaction. Due to practical difficulties of achieving the exact compaction following tolerances were also introduced.

Table 9: Number of blows required to achieve compaction

Number of blows	**Degree of Compaction (Range)**
17 (for 95)	95 $\pm$ 0.4
29 (for 98)	98 $\pm$ 0.3
45 (for 100)	100 $\pm$ 0.3

ABC specimens were casted at selected number of blows and required compactions were achieved (within the range)

3.2.3 Application of prime

Required MC -30 and CSS -1 amount were calculated as follows.

Inside area of mould = $A = \pi r^2$

r = (152.4/2) mm = $76.2 * 10^{-3}$ m, π = 3.142

A = $3.142 * (76.2*10^{-3})^2$

A = **$\underline{18241.47 \times 10^{-6}\ m^2}$**

Calculation of MC -30 amounts

Specific gravity = S_{MC-30} = 0.911

- Application Rate = 0.5 l/m^2 = 500 ml/m^2

Required volume of MC -30 = $V_{0.5}$

$V_{0.5} / A = 500$

$(V_{0.5} / 18241.47 \times 10^{-6}\ m^2) = 500$

$V_{0.5}$ = $\underline{9.12\ ml}$

Required amount of MC -30 = $M_{0.5}$

$M_{0.5} = V_{0.5} * S_{MC-30}$

$M_{0.5}$ = 9.12 * 0.911

$M_{0.5}$ = 8.31 g

$V_{0.5}$ = 9.12 ml and **$M_{0.5}$ = 8.31 g**

Similarly, calculations were repeated and obtained following results.

- Application Rate = 1.0 l/m^2 = 1000 ml/m^2

$V_{1.0}$ = 18.24 ml and **$M_{1.0}$ = 16.62 g**

- Application Rate = 1.5 l/m^2 = 1500 ml/m^2

$V_{1.5}$ = 27.36 ml and **$M_{1.5}$ = 24.93 g**

Calculation of CSS -1 amounts

Similarly, Calculations were repeated for CSS -1 as well. The specific gravity was 1.011, obtained results are shown below

$V^1_{0.5}$ = 9.12 ml and **$M^1_{0.5}$ = 9.22 g**

$V^1_{1.0}$ = 18.24 ml and **$M^1_{1.0}$ = 18.44 g**

$V^1_{1.5}$ = 27.36 ml and **$M^1_{1.5}$ = 27.66 g**

After calculation, required MC -30 and CSS -1 amount were measured.
Those amounts were poured into a bottle sprayer. After that each amount was sprayed onto specimens under Atmospheric temperature 25 ^oC – 35 ^oC
Then penetration readings were taken from cross sections of specimens using foot ruler or Vernier caliper at 6h, 12h, 18h, 24h and 30h time intervals. Number of readings were taken for a selected cross sectional profile and got the average.

Figure 15: A cross section I

Figure 14: A cross section II

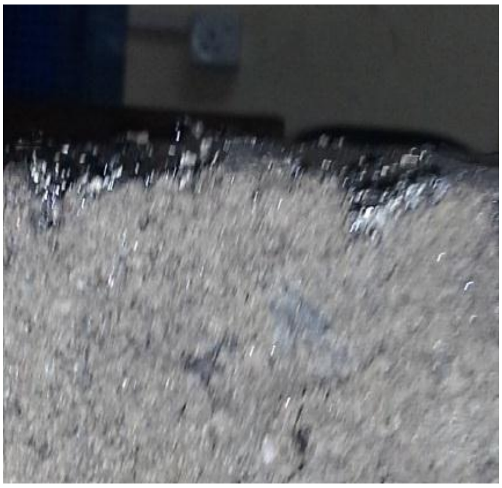

Figure 17: A cross section III

Figure 16: A cross section IV

Figure 18: Neglected areas for measurements

4. RESULTS AND DISCUSSION

4.1 Penetration results for MC -30

- Applying Rate 0.5 l/m^2

Table 10: MC -30 Penetration readings for applying rate 0.5 l/m^2

Degree of Compaction (%)	Penetration (mm)				
	6h	**12h**	**18h**	**24h**	**30h**
95	2.5	4.0	5.0	5.0	5.0
98	2.5	3.5	4.0	4.5	4.5
100	2.0	3.0	4.0	4.0	4.0

- Applying Rate 1.0 l/m^2

Table 11: MC -30 Penetration readings for applying rate 1.0 l/m^2

Degree of Compaction (%)	Penetration (mm)				
	6h	**12h**	**18h**	**24h**	**30h**
95	4.5	6.5	7.5	8.0	8.0
98	3.5	6.0	7.0	7.5	7.5
100	3.5	6.0	6.5	7.0	7.0

- Applying Rate 1.5 l/m^2

Table 12: MC -30 Penetration readings for applying rate 1.5 l/m^2

Degree of Compaction (%)	Penetration (mm)				
	6h	**12h**	**18h**	**24h**	**30h**
95	5.0	7.5	9.5	10.0	11.0
98	4.5	7.0	8.5	9.5	9.5
100	4.5	7.0	8.0	9.0	9.0

- Maximum penetration achieved with curing time

Table 13: Maximum penetration of MC -30 and required curing time

Degree of Compaction (%)	Maximum Penetration with curing time					
	0.5 l/m^2		**1.0 l/m^2**		**1.5 l/m^2**	
	Maximum Penetration (mm)	Curing Time (h)	Maximum Penetration (mm)	Curing Time (h)	Maximum Penetration (mm)	Curing Time (h)
95	5.0	18	8.0	24	11.0	30
98	4.5	24	7.5	24	9.5	24
100	4.0	18	7.0	24	9.0	24

Table 13 shows maximum penetration achieved for MC -30 and the required curing time to achieve it. The maximum penetration can be considered as the penetration requirement for relevant degree of compaction and the applying rate at respective curing time. The curing time is the most crucial factor here as traffic or sand sealing should not be allowed until that to achieve the penetration.

The common curing time was selected as 24h. This was introduced to make requirements simple and common. The required curing time 24h is not sufficient only for 95% compaction and 1.5 l/m^2 application rate. There The curing requirement is 30h, but 95% of degree of compaction is not applied for real construction works as the minimum required ABC compaction stated at ICATAD specification is 98%. And the MC -30 penetration for ABC 95% of degree of compaction at 24h curing time for 1.5 l/m ^{2} applying rate is 10.5 mm, which is only 0.5 mm deficient from penetration achievement at 30h cured base. So 24h was selected as the common curing requirement for MC -30.

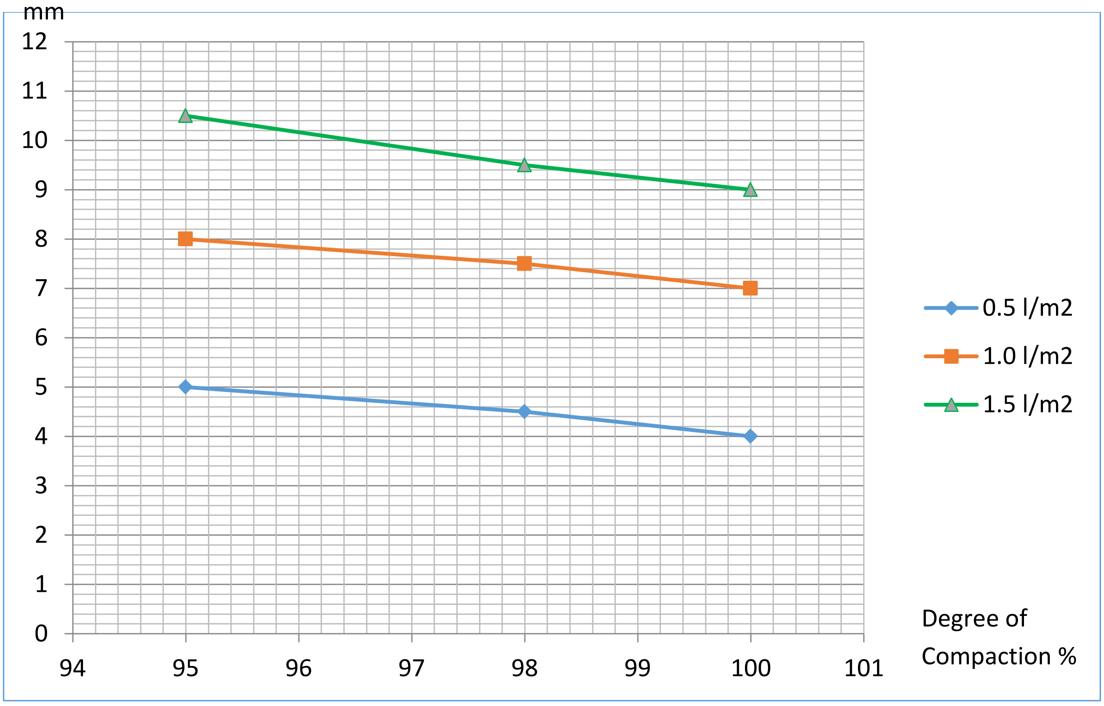

Figure 19: Penetration requirement at common curing time MC -30

4.2 Penetration results for CSS -1

- Applying Rate 0.5 l/m^2

Table 14: CSS -1 Penetration readings for applying rate 0.5 l/m^2

Degree of Compaction (%)	Penetration (mm)				
	6h	**12h**	**18h**	**24h**	**30h**
95	2.0	3.5	4.0	4.5	4.5
98	2.5	3.5	4.0	4.5	4.5
100	2.0	3.0	4.0	4.0	4.0

- Applying Rate 1.0 l/m^2

Table 15: CSS -1 Penetration readings for applying rate 1.0 l/m^2

Degree of Compaction (%)	Penetration (mm)				
	6h	**12h**	**18h**	**24h**	**30h**
95	4.0	6.0	7.0	8.0	8.0

98	3.0	6.0	6.5	7.0	7.0
100	3.0	6.5	6.5	7.0	7.0

- Applying Rate 1.5 l/m^2

Table 16: CSS -1 Penetration readings for applying rate 1.5 l/m^2

Degree of Compaction (%)	Penetration (mm)				
	6h	**12h**	**18h**	**24h**	**30h**
95	5.0	7.0	9.0	10.0	10.0
98	4.5	7.0	8.0	9.0	9.5
100	4.5	7.0	8.0	8.5	8.5

- Maximum penetration achieved with curing time

Table 17: Maximum penetration of CSS -1 and required curing time

Degree of Compaction (%)	Maximum Penetration with curing time					
	0.5 l/m^2		**1.0 l/m^2**		**1.5 l/m^2**	
	Maximum Penetration (mm)	Curing Time (h)	Maximum Penetration (mm)	Curing Time (h)	Maximum Penetration (mm)	Curing Time (h)
95	4.5	24	8.0	24	10.0	24
98	4.5	24	7.0	24	9.5	30
100	4.0	18	7.0	24	8.5	24

The common curing time was selected as 24h for CSS -1 as well. The 24h curing is not enough for 98% ABC compaction with 1.5 l/m^2 applying rate. 30h of curing is required, but for 24h of curing gives only 0.5mm deficient penetration. So the common curing time was selected as 24h.

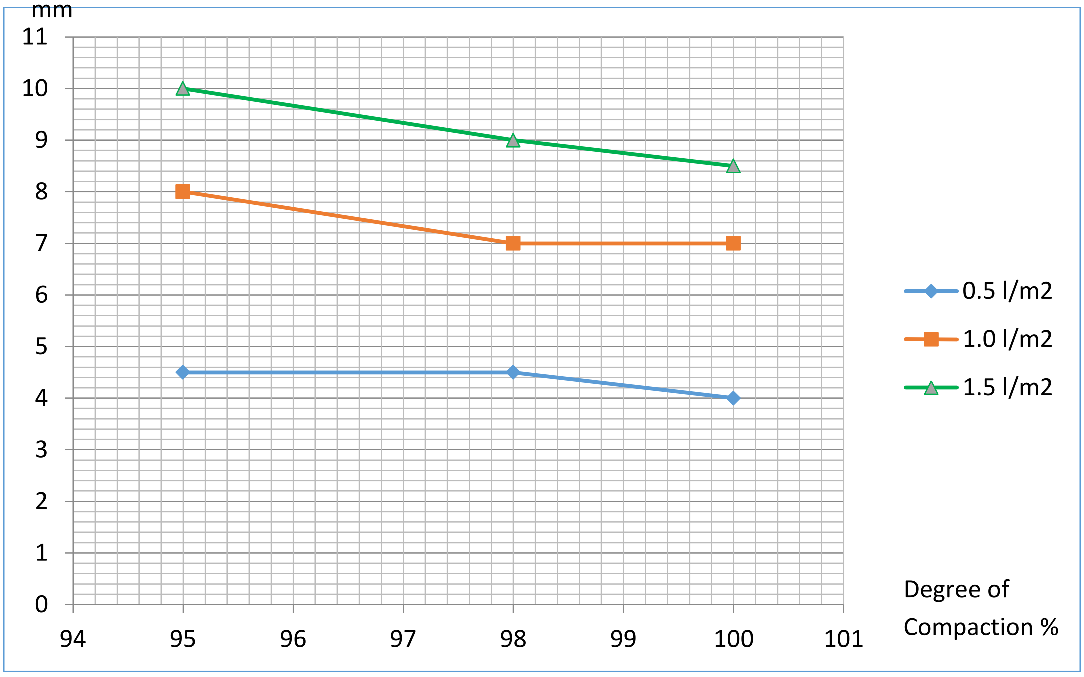

Figure 20: Penetration requirement at common curing time CSS -1

4.3 Comparison of results

- Rate of Application - 0.5 l/m^2 and curing time of 24h

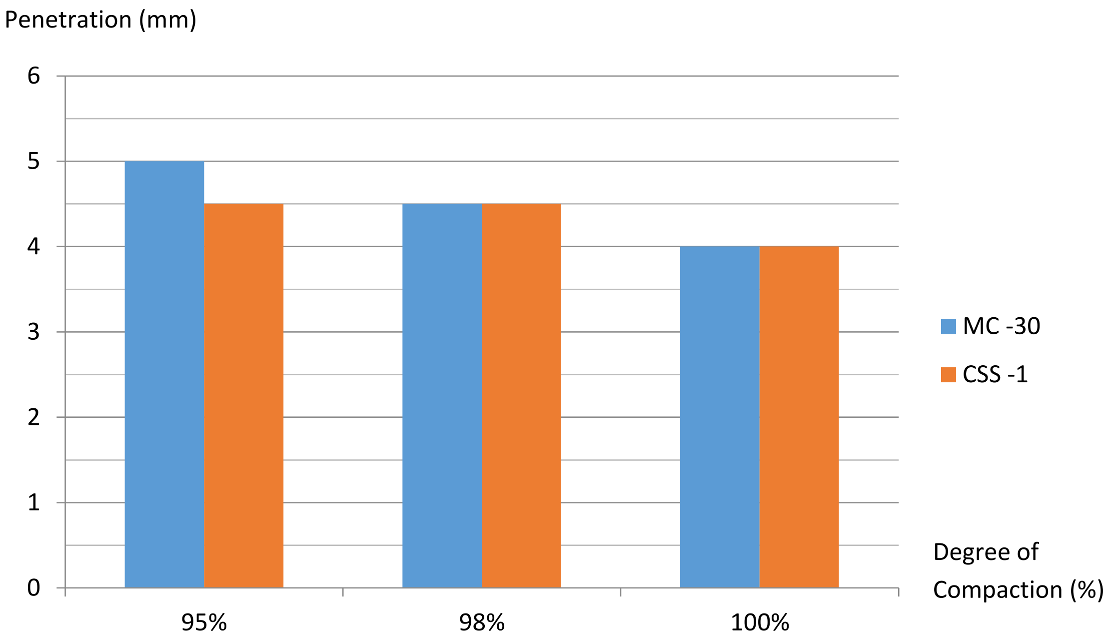

Figure 21: Comparison of 0.5 l/m^2 application rate penetration results

- Rate of Application - 1.0 l/m^2 and curing time of 24h

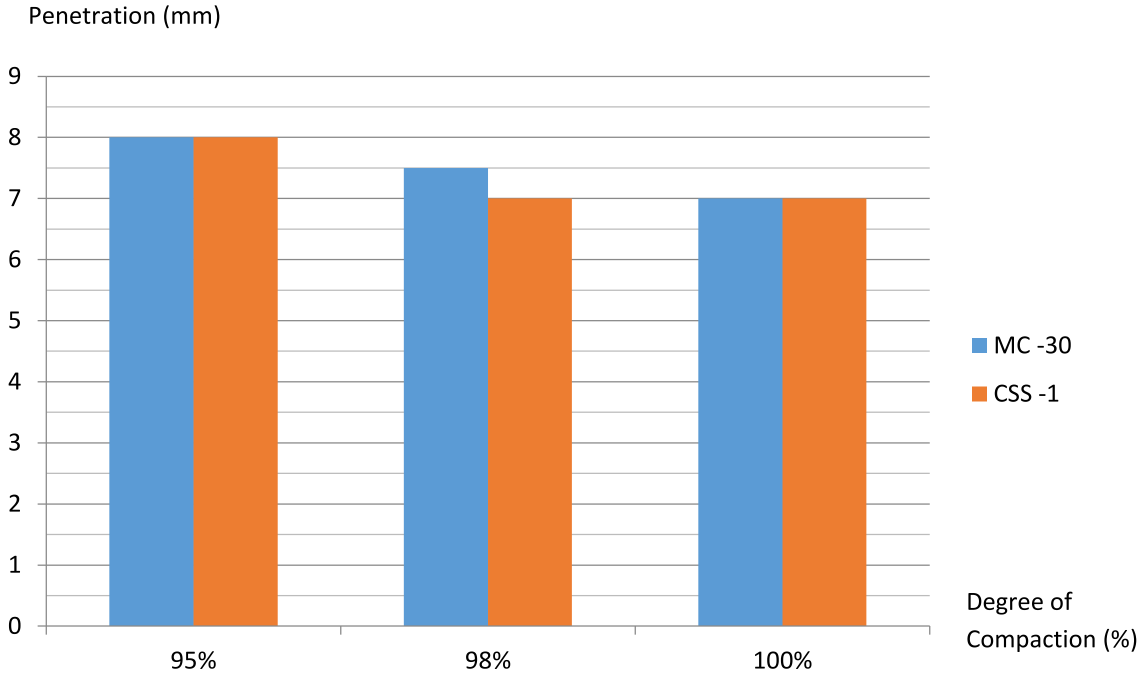

Figure 22: Comparison of 1.0 l/m^2 application rate penetration results

- Rate of Application - 1.5 l/m^2 and curing time of 24h

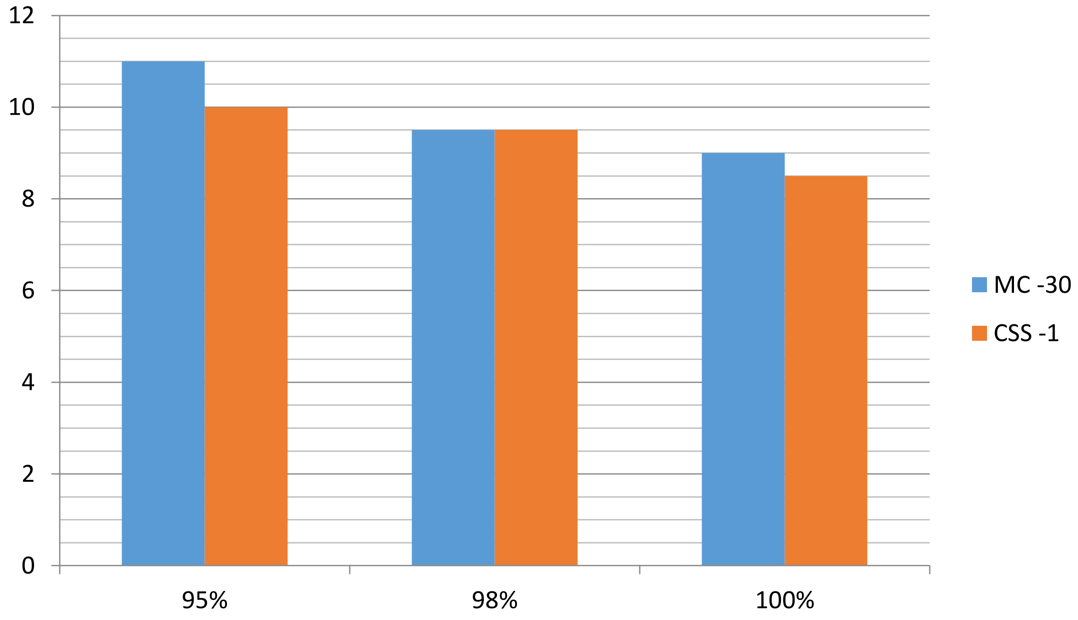

Figure 23: Comparison of 1.5 l/m^2 application rate penetration results

4.4 Selection of application rate

Adequate penetration to be effective has been reported as a minimum of 5 to 10 mm (0.25 to 0.5 in) (Cross & Shrestha, 2005). So the minimum penetration requirement can be taken as 5 mm.

According to the penetration results obtained for MC -30, lowest penetration readings were achieved at 100% base compaction at the 24h common required curing time. The Figure 24 shows the graph between the application rate and the lowest penetrations achieved for MC -30 at 24h curing period for all base compactions considered.

Table 18: Lowest penetration of MC 30 against application rate

The application rate (l/m^2)	The minimum penetration achieved (mm)
0.5	4.0
1.0	7.0
1.5	9.0

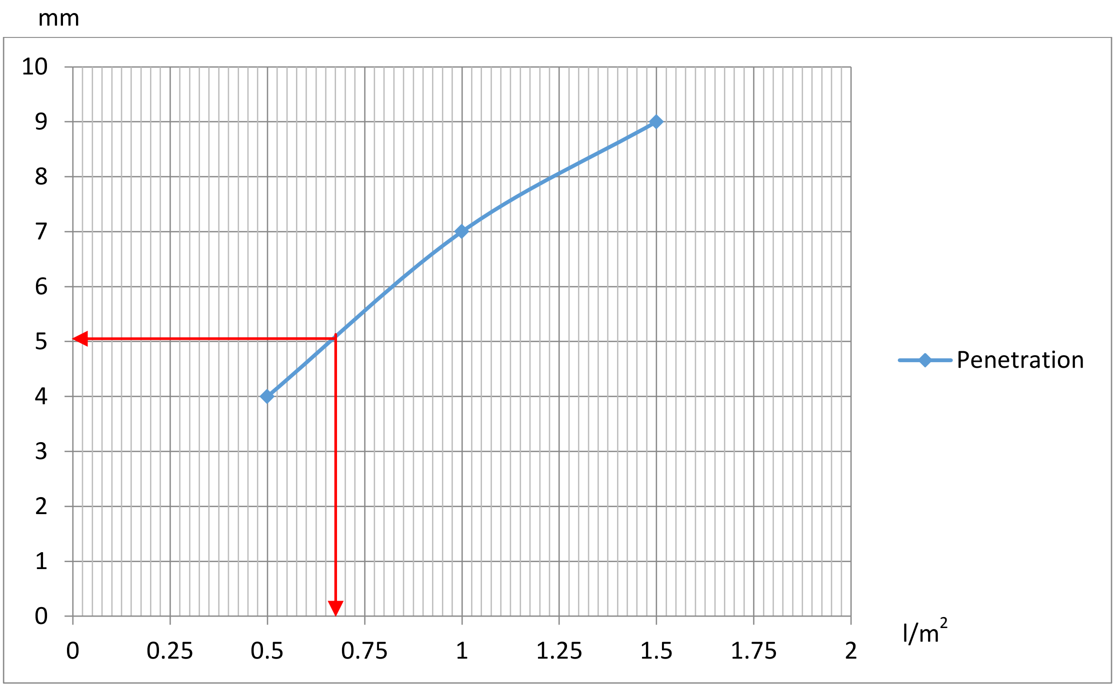

Figure 24: Lowest penetrations for MC -30 against application rate

- According to the Figure the minimum application rate of MC -30 to achieve the 0.5 mm penetration is 0.65 l/m^2.

According to the penetration results obtained for CSS -1, Minimum penetration readings were achieved at 100% base compaction at the 24h common required curing time. The Figure 25 shows the graph between the application rate and the minimum penetration achieved for CSS -1 at 24h curing period for all base compactions considered.

Table 19: Lowest penetration of CSS-1 against application rate

The application rate (l/m^2)	The minimum penetration achieved (mm)
0.5	4.0
1.0	7.0
1.5	8.5

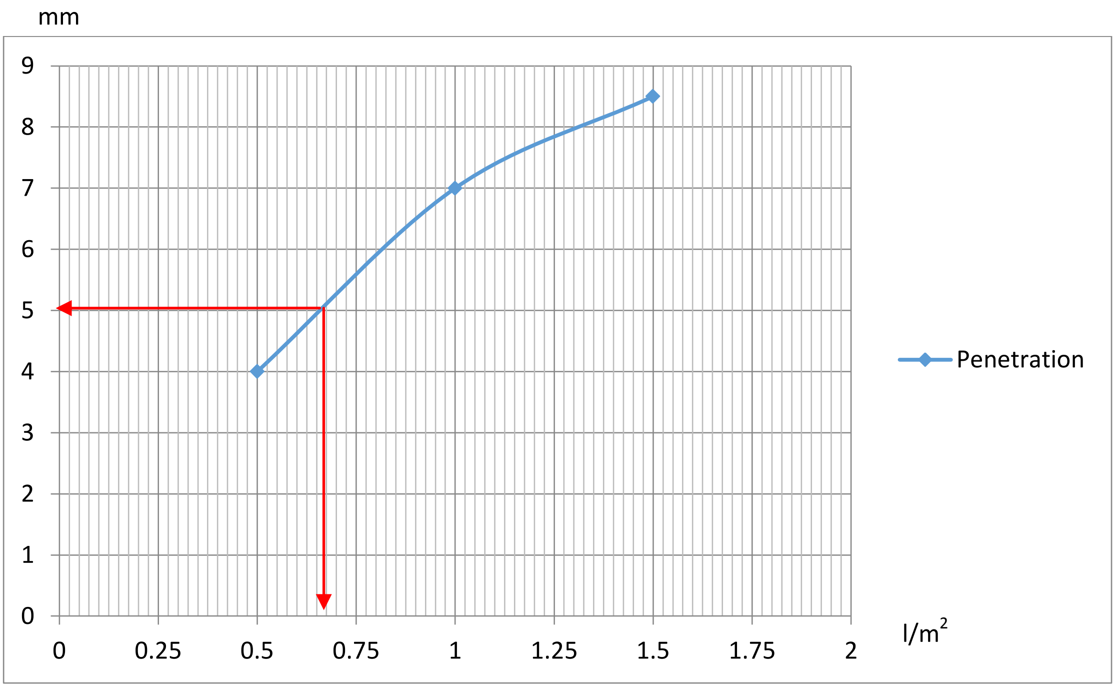

Figure 25: Lowest penetrations obtained for CSS -1 against application rate

- According to the Figure the minimum application rate of CSS -1 to achieve the 0.5 mm penetration is 0.675 l/m^2.

5. CONCLUSION AND RECOMMENDATIONS

The common required curing time for both MC -30 and CSS -1 is 24h under the scope of the study. So traffic or the sand sealing should not be allowed up to 24h by any means. By reviewing penetration results it was found that MC -30 shows slightly higher penetrations at some time intervals, so it makes MC -30 a slightly better type of prime than CSS -1 in terms of penetration. So MC -30 is recommended over CSS -1 in terms of penetration into the base.

Penetration for any given application rate between 0.5 l/m^2 - 1.5 l/m^2 and ABC compaction between 95% - 100% can be obtained from the graph. Penetration readings for MC -30 and CSS -1 for application rates from 0.5 l/m^2 to 1.5 l/m^2 vary within a range of 4 mm - 10.5 mm and 4 mm - 10 mm respectively. Adequate penetration to be effective has been reported as a minimum of 5 to 10 mm (0.25 to 0.5 in) (Cross & Shrestha, 2005). So the recommended minimum application rate is 0.65 l/m^2 for MC 30 and for CSS-1 it is 0.675 l/m^2.

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