



An Experimental Investigation of the Hydraulic and Durability Properties of Cement Treated Permeable Basecourses (CTPBs)

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Abstract: An experimental program was conducted to determine the hydraulic and durability properties of cement treated permeable bases using three different aggregate types, two gradations types and three targeted percent air voids content of 15, 25, and 35. It was observed that the CTPBs does have appreciable coefficient of hydraulic conductivity but that both the freeze-thaw and unconfined compressive test does not give any meaningful indication of the durability of CTPBs since the differences in UCS values between the control and conditioned samples can be attributed to differences in percent air voids content rather than due to the effect of freeze-thaw environmental procedure they were subjected to.

Keywords: Hydraulic, Durability, Pavement, CTPBs, Open-graded, aggregate

I. Introduction

The use of permeable basecourses as the principal drainage layer within a pavement's structural section has been growing in use over the years due to their perceived role of drastically reducing the time the pavement is exposed to saturated conditions. Their application has led to significant reduction in the occurrence of moisture-related distresses in both flexible and rigid pavements. However, due to the stability problems associated with pavement sections containing unbound open-graded drainage layers, many highway agencies have resorted to the use of bound open-graded basecourses. Treatment of the unbound open-graded has been done with the use of both asphalt and cement but the asphalt treated permeable basecourses has been the most prominent.

However, studies have found that after years of apparently satisfactory service, distresses have been observed in some pavements with free-draining bases even when they meet open-graded specifications. It has been observed that drainage from these layers is slowing over time and there is now increasing concern as to how long the coefficient of hydraulic conductivity of open-graded base course can be maintained as the pavement ages. Also some base course materials that do meet the required gradation specification for use as free-draining bases have only produced fair to poor drainage. This has led to the observance of premature joint deterioration, faulting and cracks in pavement sections containing asphalt treated open-graded bases.

In an effort to produce non-erodible and drainable base layer, many state highway agencies have moved from the traditional dense graded base course gradation specifications to more open graded base course specifications that allow for greater drainage in the pavement sub-layers. One major reason for this transition is due to the fact that dense gradations, even though they offer stiffer bases with good constructability have serious long term stability problems as a result of prolonged saturation of the pavement structural section leading the stiffness as the pavement ages (Forsyth RA, 1994). However, one prominent drawback of these open-graded specifications is producing base layers that are difficult to construct and less stable under traffic and environmental loads. In order to overcome these drawbacks, some of these open-graded materials are now being stabilized with cement. (Hansen et al. 2009).

However, studies have found that after years of apparently satisfactory service, distresses have been observed in some pavements with free-draining bases even when they meet open-graded specifications. It has been observed that drainage from these layers is slowing over time and there is now increasing concern as to how long the coefficient of hydraulic conductivity of open-graded base course can be maintained as the pavement ages (Kazmierowski et al, 94). Also some base course materials that do meet the required gradation specification for use as free-draining bases have only produced fair to poor drainage. This has led to the observance of premature joint deterioration, faulting and cracks in pavement sections containing these open-graded bases (Bennet et al. 2007). As a result of these problems concerns have been raised about the durability of cement treated permeable bases (CTPBs) especially when they are subjected to cyclic environmental conditions like freeze-thaw and wetting/drying and how this might affect their contribution to pavement performance.

II. Experiment Programme

The experimental program was carried out in two phases. A hydraulic conductivity testing program geared towards measuring the laboratory K value of the different samples and a durability testing program for measuring the resistance of the various samples to certain environmental variables like freeze-thaw and moisture damage.

Aggregate Base Materials

Three aggregate base materials that were used to prepare the asphalt treated open-graded samples were two natural aggregates and one recycled aggregate. The natural aggregates were Natural Gravel and Dolomite while the recycled material was Recycled Crushed Concrete.

Table 1: Aggregate material properties

Material type	SSD, specific gravity	Absorption (%)
Natural gravel	2.65	2.62
Limestone	2.80	2.8
Recycled Portland cement concrete	2.53	5.3

Stabilizing Agents

For this research program Type 1 cement was utilized for the cement treated open-graded samples.

Aggregates' Gradations

Two gradation types were used namely the AASHTO #67 and MDOT 5G. These are shown in Table 2:

Table 2: Aggregate specifications – percent finer by weight

Sieve Size (inches)	AASHTO'S NO.67	Michigan 5G
2 1/2		
2		
1 1/2		100
1	100	
3/4	90-100	
1/2		0-90
3/8	20-55	
#4	0-10	0-8
#8	0-5	
#16		
#30		
#40		
#50		
#200		0-3

Grain-size Distribution - Base Course

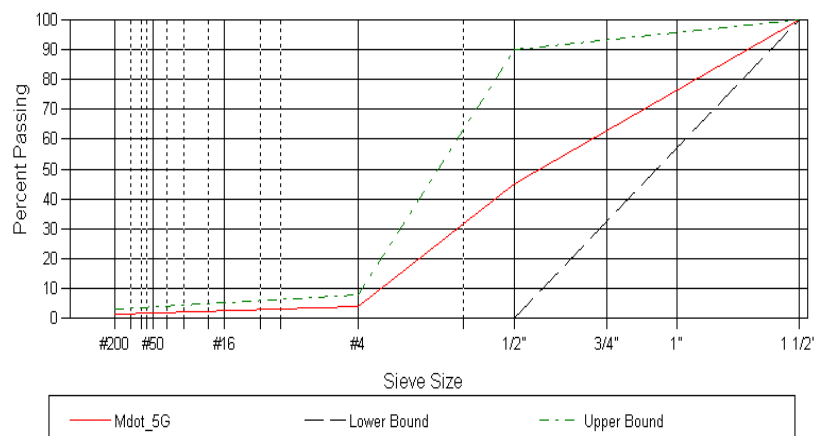


Figure 1: Grain-size distribution of Michigan stabilized 5G aggregate

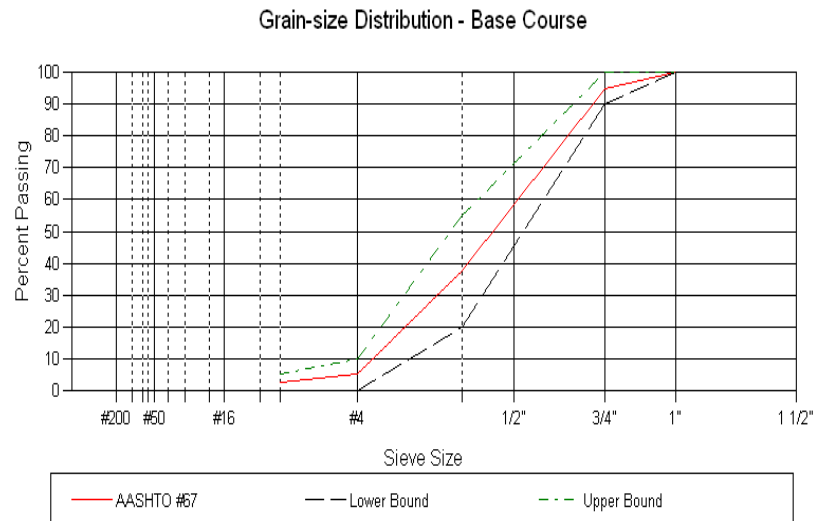


Figure 2: Grain-size distribution of AASHTO #67 aggregate

III. Mix Design and Testing Procedure for Cement Treated Permeable Bases (CTPBs)

In order to make the testing program for the laboratory hydraulic conductivity yield representative results, the mix design used in this research was made as far as possible to be practically identical to that use in actual construction projects. For this research project, only one cement content i.e. 200 lb/yd³ was used and three target air voids content of 35%, 25% and 15%. These target percent air voids content were the defining criterion of the mixed design instead of the Unconfined Compressive Strength (UCS). A constant water/cement ratio of 0.36 was used for all the mixes.

Table 3 gives the mix proportions for the CTPB

Table 3: Mix proportion for CTPB

Mixture ID.	Cement Content (lb/yd ³)	Design air void content (%)
1	200	15
2	200	25
3	200	35

Based on this design mix, 1 cubic yard of cement treated open-graded material with a design percent air void of 15% will contain 200 lbs of cement, 72 lbs of water and 3622 lbs of coarse aggregate. For a 6”*12” concrete mold and batch mix for four samples, the appropriate quantities of cement, water and coarse aggregate were determined. The absorption capacity of the coarse aggregate fractions was taking into consideration in arriving at the final amount of water to be added. The purpose of doing three mix types was to find a mix design that will meet minimum acceptable stability and drainability criteria. All the preliminary testing on the aggregates was done in accordance with the ASTM standards of the respective tests. Table 3.6 gives the physical characteristics of the three open-graded aggregate materials used in this research project.

Four samples for each mix type were prepared leading to a total of 72 cement treated open-graded materials. The samples were tested as follows:

- o All four specimens for each mix type were tested for hydraulic conductivity after 1 day curing period. The specimens were returned to the curing after the hydraulic conductivity testing.
- o Two samples were tested for the 7-day unconfined compressive strength (UCS)
- o Two samples were subjected for 10 Freeze/Thaw cycles after the 7 day curing period.
- o After the Freeze/Thaw procedure, the specimens were weighed to determine any weight loss and then tested for UCS to determine any strength loss as a result of the F/T process.

IV. Specimen Compaction

Since three design air voids content were targeted, different compaction efforts were employed in order to produce samples of the required percent air void content. As a result many trial mixes were made with different compaction efforts and the corresponding percent air void content measured. The procedure was continued until a compaction effort that produced the closest percent air void content to that of the design air void content was reached. After achieving the desired degree of compaction, the compacted

CTPB specimens were then tested for four key performance characteristics that are in the estimation of this researcher paramount to the characterization of cement treated drainage layers. These are the unit weight, coefficient of hydraulic conductivity, unconfined compressive strength for both control and condition specimens and the effective air void content.

After making several the trial compaction runs, the following level of compactive efforts were developed:

1. CTPB mixes with air voids content of 15%- 3 layers, 25 Marshall Hammer blows per layer and rodded 25 times per layer.
 2. CTPB mixes Air voids content of 25%- 2 layers, rodded 25 times per layer, 20 Marshall Hammer blows per layer.
 3. CTPB mixes with air voids content of 35%- 2 layers, no rodding, 2 Marshall hammer blows per layer
- After compaction, the samples were allowed to set for a day and then removed from the molds, marked, weighed, tested for the coefficient of hydraulic conductivity and then wet cure for a period of 7 days.

V. Testing procedure for cement-treated Open-Graded Aggregate Materials

Determination of unit weights and effective air voids content of compacted CTPB samples: There are currently no standard testing procedures for measuring the four performance characteristics of compacted open-graded concrete materials. However, a procedure developed by Crouch et al (2003) to measure similar material properties for pervious concrete was used in this research to determine the compacted unit weight and the effective air voids content of the compacted CTPB samples.

Even though air voids content of 15%, 25% and 35% were used in the mix design calculations, the effective air voids of the compacted samples is the parameter of interest. The effective air voids content represents the pore spaces that are available for drainage. It is calculated from the equation:

$$\text{Avoid \%} = 100(1 - G_{mb}/G_{mm})$$

Where G_{mb} = bulk specific gravity of the CTPB sample; G_{mm} = Theoretical maximum specific gravity

Experimental procedure for conducting the hydraulic conductivity test was done strictly in accordance with ASTM D5068 "*Determination of Hydraulic Conductivity of Porous Stone Using a Flexwall Permeameter*". For each specimen, five hydraulic conductivity measurements were made and then averaged. Standard practice also requires that the coefficient of hydraulic conductivity be reported to a base temperature of 20 degrees Celsius, the temperature for each test was recorded and correction to the hydraulic conductivity value was made using the appropriate formula. Two correction factors were applied to the measured K value in order to arrive at the corrected measured K value. Corrections were made for the hydraulic conductivity of the ceramic porous stones and for the head loss across the specimen. The hydraulic conductivity of the porous ceramic stones was measured by setting up the flexwall permeameter using the two porous stones without the specimen in it. The head loss through the specimen was a dummy sample of similar dimension as the actual specimen made of cast steel was fitted in the laboratory set up using identical procedures was used for the actual specimen. For this case it was assumed that the head loss across the dummy sample is negligible so that head loss measured will be attributed only to that of the system (Smith 2004).

VI. Durability Testing For CTPBs

The freeze-thaw durability testing was performed in accordance with the procedures outlined in ASTM D560. The criterion used to measure the resistance to freeze-thaw is the total weight loss after completion of the prescribed freeze-thaw cycles. In addition to the recommended weight loss criterion, the reduction/increase of the Unconfined Compressive Strength (UCS) due to the freeze-thaw conditioning was also determined. Even though some authors don't considered the UCS as an acceptance for cement-treated permeable bases in the same way as it applies to normal concrete, for this research study though, the percent reduction in the UCS due to the environmental conditioning of freeze-thaw was considered a measure of the stability and resistance of the cement-treated samples to disintegration. . Four CTPB samples for each mix type were divided into two groups labeled "control" group and "conditioned" group. The two control specimens were then tested for UCS after coefficient of hydraulic conductivity tests have been performed. Two other CTPB specimens were conditioned and underwent freeze-thaw in accordance with the provisions of ASTM D560. After undergoing the prescribed number of F-T cycles, the samples were weighed to determine the percent weight loss. The UCS test was afterwards conducted on the "conditioned" samples. The coefficient of hydraulic test using the flexwall permeameter was however conducted on all four CTPB samples.

Two notable modifications were made to ASTM D 560 with regards to the method of compaction and the number of freeze/thaw cycles. The thickness of the CTPB normally varies between 3-6 inches, with 4 inches being the most common. For this research however, a thickness of 12 inches was selected as this height was deem adequate to achieve the three targeted range of air void content. Therefore the prescribed standard proctor compaction method was not employed since it would have lead to excessive particle breakage that may have lead to erroneous tests results which are not representative of the open-graded nature

of these specimens.

Furthermore, in accordance with ASTM specification for the freeze/thaw test 12 freeze/thaw cycles was specified. However, 10 F/T cycles were used for this testing program because according to Dempsey (1972) the number of F/T cycles chosen for the durability test should be related to geographical location, climatic conditions and position of the stabilized layer in the pavement. Since the drainage layer for most part is located just underneath the pavement surface, it is not subjected to the same freeze/thaw cycles as the subgrade and as such a less severe F/T cycles may be appropriate for the drainage layer. The number of F/T cycles was also reduced to 10 in order to reduce the time for the experimental program with the assumption being that 10 F/T cycles can give a meaningful value of the resistance of these materials to freeze-thaw.

Table 4: Coefficient of hydraulic conductivity of CTPB Samples

Specimen	Nominal content (lb/yd ³)	Cement W/C	K (cm/s)
RC_5G_15	200	0.36	1.02
RC_5G_25	200	0.36	1.50
RC_5G_35	200	0.36	2.66
RC_67_15	200	0.36	0.80
RC_67_25	200	0.36	1.14
RC_67_35	200	0.36	2.17
NG_5G_15	200	0.36	1.22
NG_5G_25	200	0.36	2.06
NG_5G_35	200	0.36	3.35
NG_67_15	200	0.36	1.06
NG_67_25	200	0.36	1.39
NG_67_35	200	0.36	2.88
DL_5G_15	200	0.36	1.29
DL_5G_25	200	0.36	2.53
DL_5G_35	200	0.36	3.84
DL_67_15	200	0.36	1.01
DL_67_25	200	0.36	2.04
DL_67_35	200	0.36	2.96

Table 5: Weight and Strength Losses per sample

Sample ID	Weight before F/T (g)	Measured % air voids content	Weight after F/T (g)	Weight loss (%)	UCS of control samples (7-day strength) psi	UCS of condition samples, psi	Strength loss (%)
RC_5G_15_1	16700		-	-	827.3		
RC_5G_15_2	16712		-	-	819.6		
RC_5G_15_3	16705		16704.6	0		832.4	0.6
RC_5G_15_4	16710		16709.8	0		824.5	0.6
RC_5G_25_1	16214		-	-	729.1		
RC_5G_25_2	16220		-	-	737.6		
RC_5G_25_3	16226		16225	0.006		735.2	0.8
RC_5G_25_4	16210		16210	0.0		740.4	0.4
RC_5G_35_1	15980		-	-	504.2		
RC_5G_35_2	15983		-	-	510.3		
RC_5G_35_3	15977		15976	0.006		510.7	1.3
RC_5G_35_4	15986		15986	0.0		512.3	0.4
RC_67_15_1	16728		-	-	909.6		
RC_67_15_2	16725		-	-	915.3		
RC_67_15_3	16730		16729	0.006		915.4	0.6
RC_67_15_4	16725		16723	0.012		918.4	0.3
RC_67_25_1	16245		-	-	827.2		
RC_67_25_2	16248		-	-	832.5		
RC_67_25_3	16250		16249	0.006		835.3	1.0
RC_67_25_4	16243		16241	0.012		836.4	0.5
RC_67_35_1	15992		-	-	701.8		
RC_67_35_2	15984		-	-	723.4		
RC_67_35_3	15987		15985	0.012		708.7	1.0
RC_67_35_4	15990		15988	0.012		726.3	0.4

Table 6: Weight and Strength Losses per sample (Cont.)

Sample ID	Weight before F/T (g)	Measured % air voids content	Weight after F/T (g)	Weight loss (%)	UCS of control samples, psi	UCS of condition samples, psi	Strength loss (%)
NG_5G_15_1	16825		-	-	621.8		
NG_5G_15_2	16800		-	-	604.5		
NG_5G_15_3	16810		16810	0.0		623.2	0.2
NG_5G_15_4	16814		16813	0.006		606.6	0.3
NG_5G_25_1	16735		-	-	483.8		
NG_5G_25_2	16724		-	-	492.4		
NG_5G_25_3	16700		16698	0.012		485.9	0.4
NG_5G_25_4	16716		16715	0.006		494.1	0.3
NG_5G_35_1	16230		-	-	329.6		
NG_5G_35_2	16253		-	-	318.7		
NG_5G_35_3	16310		16310	0.0		332.6	0.9
NG_5G_35_4	16285		16285	0.0		320.4	0.5
NG_67_15_1	16835		-	-	675.3		
NG_67_15_2	16840		-	-	657.3		
NG_67_15_3	16827		16825	0.012		677.9	0.4
NG_67_15_4	16830		16830	0.0		663.8	1.0
NG_67_25_1	16742		-	-	569.1		
NG_67_25_2	16750		-	-	580.4		
NG_67_25_3	16734		16734	0.0		571.1	0.4
NG_67_25_4	16753		16752	0.006		582.4	0.3
NG_67_35_1	16315		-	-	431.3		
NG_67_35_2	16325		-	-	421.4		
NG_67_35_3	16314		16314	0.0		433.4	0.5
NG_67_35_4	16333		16333	0.0		423.8	0.6

Sample ID	Weight before F/T (g)	Measured % air voids content	Weight after F/T (g)	Weight loss (%)	UCS of control samples, psi (7-day strength)	UCS of condition samples	Strength loss/gain (%)
DL_5G_15_1	16843		-	-	880		
DL_5G_15_2	16840		-	-	868.4		
DL_5G_15_3	16852		16851	0.006		883.5	0.4
DL_5G_15_4	16842		16842	0.0		876.3	0.9
DL_5G_25_1	16831		-	-	742.4		
DL_5G_25_2	16835		-	-	753.6		
DL_5G_25_3	16825		16825	0.0		746.7	0.6
DL_5G_25_4	16820		16820	0.0		756.6	0.4
DL_5G_35_1	16802		-	-	575.5		
DL_5G_35_2	16796		-	-	574.2		
DL_5G_35_3	16810		16809	0.006		577.3	0.3
DL_5G_35_4	16805		16803	0.012		576.8	0.5
DL_67_15_1	16852		-	-	969.4		
DL_67_15_2	16850		-	-	960.4		
DL_67_15_3	16864		16864	0.0		968.1	0.1
DL_67_15_4	16870		16869	0.006		971.3	1.1
DL_67_25_1	16837		-	-	813.2		
DL_67_25_2	16830		-	-	809.4		
DL_67_25_3	16831		16831	0.0		816.3	0.4
DL_67_25_4	16828		16827	0.006		811.4	0.2
DL_67_35_1	16814		-	-	712.0		
DL_67_35_2	16800		-	-	715.3		
DL_67_35_3	16803		16802	0.006		716.2	0.6
DL_67_35_4	16811		16810	0.006		717.4	0.3

VII. Conclusion

From the results of laboratory testing to determine the hydraulic, mechanical and durability characteristics of cement treated open-graded aggregate base materials, the following trends were observed:

1. All three mix types with target % air voids of 15, 25 and 35 produced coefficient of hydraulic conductivity that satisfied AASHTO minimum K value of 1000 ft/day for good drainage. This means that all three design mixes can be used to provide a drainage layer that can drain within 2 hours 50% of infiltrating moisture within the pavement structural system.
2. From a material perspective, limestone mixes have the highest K values followed by those of recycled concrete aggregate and natural gravel being the least. However the differences in K value between the K values of limestone mixes and those of natural gravel is less than an order of magnitude. Since all mix types meet the minimum accepted K value, these differences in K values between the materials is not significant enough as to warrant the selection of one material over the other on the basis of hydraulic conductivity alone.

3. From a gradation perspective, MDOT 5G gradation samples containing the larger size fractions produced higher K values for all the mix types than mixes made from AASHTO # 67 gradation. Again the difference in K value here is less than an order of magnitude even though the MDOT gradation is more open-graded gradation with a D₁₀ value almost 1.5 times that of AASHTO #67 gradation. One possible explanation for this is that MDOT 5G samples because of their larger size fractions require small amount of aggregates than the AASHTO #67 for the same volume. As a result the MDOT 5G samples will contain larger pore spaces between the aggregate particles which leads to a higher void ratio and subsequently higher measured coefficient of hydraulic conductivity than the AASHTO #67 samples.
4. Unconfined Compressive strength (UCS) results as expected are a direct function of the % air void content. For all mix types, the lower % air void content samples provided the highest UCS values. One noticeable trend though is that the difference in UCS values between a 15% and 35% air void content sample of the same material and gradation is about 25%. This is quite a significant amount especially when considering the stability of the drainage layer under the combined action of traffic and environmental loads.
5. Results from the durability testing showed that percentage weight loss is less than the established criterion of 5% for a stabilized layer underneath a concrete pavement. The maximum percent weight loss was 1%, which is far less than the prescribed 5%. This can be an indication that freeze-thaw durability criterion may not be an appropriate durability performance test for cement-treated open-graded bases.
6. Furthermore, the difference in UCS values between the control and conditioned samples can be attributed to strength gain due to age rather than the freeze-thaw conditioning process.



Measuring the K of CTPB using flexwall permeameter

CTPB samples after UCS testing

VIII. References

- [1] American Association of State Highways Transportation Officers (AASHTO) T85 2010. Standard Method of Test for Specific Gravity and Absorption of Coarse Aggregate
- [2] American Association of State Highways Transportation Officers (AASHTO) T99 2010. Standard Method of Test for Moisture-Density Relationship.
- [3] American Society for Testing and Materials (ASTM) D560 .Standard Test Methods for Freezing and Thawing of Compacted Soil-Cement Mixtures. Annual Book of ASTM Standards, Vol.08.12.09.
- [4] American Society for Testing and Materials (ASTM) D5084. Standard Test Methods for Measurement of Hydraulic Conductivity of Saturated Porous Materials Using a Flexwall Permeameter. Annual Book of ASTM Standards, Vol.08.12 2007.
- [5] Crouch L, Cates M, Dotson V, Honeycutt K, Badoe D. "Measuring the Effective Air Void Content of Portland Cement Pervious Pavements" Journal of Cement, Concrete, and Aggregates. 25: 23-30, 2003.
- [6] Dempsey B. J. "Durability Testing of Stabilized Bases" Interim Report., 1972
- [7] Forsyth RA .. "Asphalt Treated Permeable Base: Its evolution and Application" National Asphalt Pavement Association, Report Number Q117:23-30, Lanham, MD, 1994.
- [8] Kazmierowski T. J, Bradbury A, Hajek J.. " Field Evaluation of Various Types of Open-Graded Drainage Layers" Journal of Transportation Research Record 1434: 29-36, 1994.
- [9] Marks A.. "Pervious Concrete Pavement- How Important is Compressive Strength" Journal of Green Building, 3:36-43, 2008.
- [10] Mayrberger T, Hodek RJ. "Resilient Modulus at the Limits of Gradation and Varying Degrees of Saturation" Final Report Research Report RC-1497. Michigan Department of Transportation, Lansing, MI. 2007
- [11] Gupta J, Heydinger A, Randolph B.. "Permeability & Stability of Base and Subbase Materials" Ohio Department of Transportation (ODOT) Research report, 1999.
- [12] Smith N. "Permeability of Pervious Portland Cement Pavement" Master of Science Thesis, Tennessee Technological University, 2004.
- [13] R. Tangpithakul, "Study of Permeability of Base Materials. Master's Thesis, Ohio University, OH. 1997

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