

## **A COMPREHENSIVE RESEARCH ON LABORATORY PERFORMANCE OF ORGANOSILANE ADDITIVE IN BITUMINOUS MIX**

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### **Abstract**

*Investigations have been carried out in India and countries abroad to find out the properties of bitumen and bituminous mixes and by the methods by which they can be improved to cope up with the above defects of pavements and with the incorporation of certain additives or blend of additives. These additives that are added to enhance the binders are called “Bitumen Modifiers” and the bitumen premixed with these modifiers is known as “Modified Bitumen”. Modified bitumen’s performance depends upon the degree of modifications and type of additives and modification process used. The time period of next renewal is expected to extend by 50 per cent in case of surfacing with modified bitumen as compared to normal period indicated for conventional bitumen. For example, if normal renewal cycle is 4 years, this may be enhanced to 6 years in case of modified bitumen. Full scale performance studies carried out under the ages of Ministry of Road Transport and Highways, New Delhi, Central Road Research Institute , New Delhi , Highway Research Station, Chennai, Rubber Board, Kottayam, Gujarat Engineering Research Institute, Vadodara and Kerala Public Works Department revealed that the use of Modified Bitumen in construction/ maintenance of bituminous roads is cost effective, when life cycle cost is taken into consideration. The choice will in nut shell depend ultimately upon life cycle costing of overlays and renewals using ordinary bitumen and modified bitumen for prevailing traffic and climatic conditions. It will also depend upon the type of the pavement constructed. The need for bituminous binders has aroused due to the pavement failures. Pavement failures are one of the important issues in the entire pavement system. The failure can be due to a lot of issues, such as:*

- *Defects of the materials used*
- *Defects in the construction method*
- *Defects in quality control during construction*
- *Inadequate surface or sub surface drainage*
- *Increase in magnitude of wheel loads and the number of load repetitions due to increase in traffic volume*

**Key words:** *Bituminous mix; Marshall Test; Stability; Aggregates; zycotherm.*

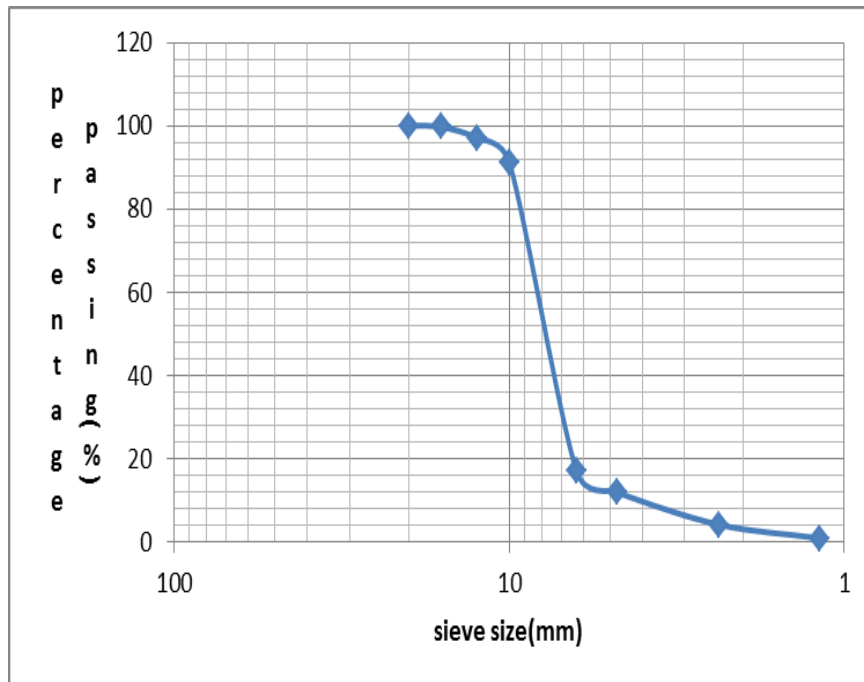
### **1. Introduction**

Bitumen is a mixture of different organic materials, mostly of carbon and hydrogen. It is produced through vacuum distillation of petroleum. The bitumen binder can go through various problems in the field such as stripping from the aggregate, which can lead to cracking, rutting, depressions and potholes etc. Thus the binders can be modified by adding an additive to enhance its various properties. This binder in which an additive is added to make it better in its performance is called as modified binder. Modified binders are those bituminous binders whose properties have been modified by the use of additives.

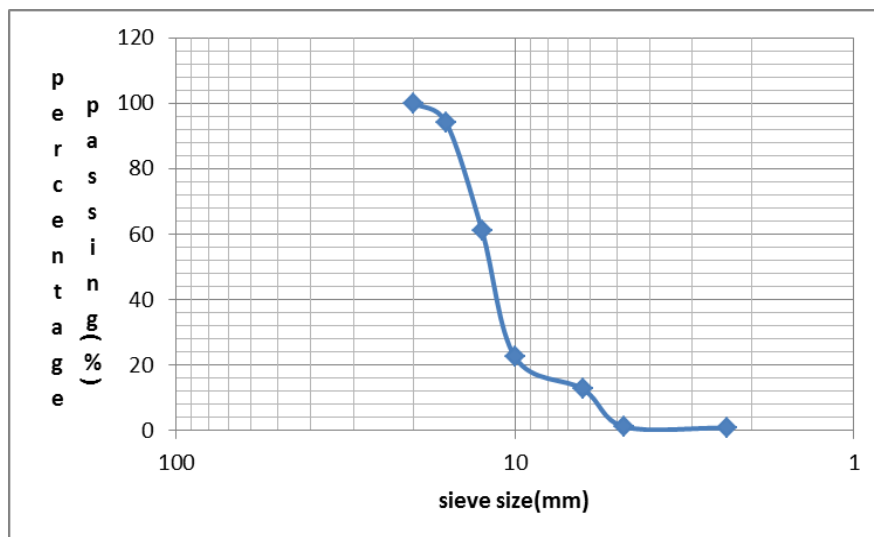
#### *1.1. Materials and Methodology*

The coarse aggregates for this study are taken from Ganderbal stone quarry and have following properties:

- i) **Nominal size = 10 mm**



**Fig. 1: Sieve analysis of 10 mm nominal size aggregates**



**Fig. 2: Sieve analysis of 20 mm nominal size aggregates**

**a) FINE AGGREGATES**

Fine aggregates generally consist of natural sand or crushed stone with most particles passing through a 3/8-inch sieve. Coarse aggregates are any particles greater than 0.19 inch, but generally range between 3/8 and 1.5 inches in diameter. They shall be the fraction passing 2.36 mm sieve and retained on 75 micron sieve, consisting of crusher run screening etc. They should be clean, hard, durable and free from any deleterious substances.

**b) FILLER**

Filler can consist of finely divided mineral matter such as rock, hydrated lime or cement. It should be free from impurities. Cement or hydrated lime is not required when the gravel is limestone. In this study the filler used was 53 Grade OPC.

**c) STONE DUST**

Quarry process, also known as QP, dense grade aggregate (DGA), crusher run and road stone, is a combination of small, 3/4-inch-or-less crushed broken stone and stone dust.

**Physical**

| S NO. | TEST  | TEST METHOD     | REQUIREMENT                 | OBSERVED VALUE       |
|-------|---|-----------------|-----------------------------|----------------------|
| 1     | Los Angeles Abrasion Value                        | IS:2386(Part-4) | 40% Maximum                 | 13.08% & 18.92%      |
| 2     | Aggregate Impact Value                            | IS:2386(Part-4) | 30% Maximum                 | 11.25% & 10%         |
| 3     | Combined flakiness and elongation Indices         | IS:2386(Part-1) | 30% Maximum                 | 20.15% & 20.38%      |
| 4     | Coating & stripping of bitumen aggregate mixtures | AASTO T 182     | 10% Minimum stripping value | 2%                   |
| 5     | Soundness(Loss with sodium sulphate)              | IS:2386(Part 5) | 12% Maximum                 | 10%                  |
| 6     | Specific gravity and water absorption             | IS:2386(Part 3) | 2.5-3.2 and 2% Maximum      | 2.91 & 1%, 3.07 & 1% |

*1.2 Physical requirements and the observed values of the coarse aggregates used in the study*

| S NO. | TEST  | TEST METHOD     | REQUIREMENT                 | OBSERVED VALUE       |
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| 1     | Los Angeles Abrasion Value                        | IS:2386(Part-4) | 40% Maximum                 | 13.08% & 18.92%      |
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*1.3 Physical requirements as per IS – 73 and the observed values of the binder used in the study*

| S NO. | CHARACTERISTICS                                   | PAVING GRADE REQUIREMENT (VG 10) | OBSERVED VALUES |
|-------|---|----------------------------------|-----------------|
| 1     | Penetration at 25 C,100 g, 50 s, 0.1 mm, Min      | 80                               | 60/70           |
| 2     | Absolute viscosity at 60 C , Poises               | 800-1200                         | 1072.3          |
| 3     | Kinematic viscosity at 135 C, cSt, Min            | 250                              | 265.27          |
| 4     | Flash point(open cup ), C, Min                    | 220                              | 240             |
| 5     | Softening point, C, Min                           | 40                               | 48              |
| 6     | Specific gravity                                  | 0.97-1.02                        | 1.01            |
| 7     | Test on residue from rolling thin film oven test: |                                  |                 |
|       | a) Viscosity ratio at 60 C, Max                   | 4.0                              | 1.029           |
|       | b) Ductility at 25 C, cm, Min                     | 75                               | Above 100       |

1.4 Proportioning of the materials used for the design mix

|                             | 20mm   | 10mm   | Fine Aggt sand | 4.75mm<br>down n Dust | Filler | DBC 40mm (2)     |               |     |           |          |     |
|-----------------------------|--------|--------|----------------|-----------------------|--------|------------------|---------------|-----|-----------|----------|-----|
| PROPORTIONING OF AGGREGATES |        |        |                |                       |        |                  |               |     |           |          |     |
| Size                        | A      | B      | C              | D                     | E      | LL               | UL            | MID | GRADATION | SE       |     |
| 26.50                       | 100    | 100    | 100            | 100                   | 100    | 100              | 100           | 100 | 100       | 0.00     |     |
| 19.00                       | 91     | 100    | 100            | 100                   | 100    | 100              | 100           | 100 | 100       | 0.00     |     |
| 13.20                       | 31     | 98     | 100            | 100                   | 100    | 90               | 100           | 95  | 99        | 18.30    |     |
| 9.50                        | 3      | 52     | 98             | 99                    | 100    | 70               | 88            | 79  | 80        | 0.28     |     |
| 4.75                        | 3      | 4      | 80             | 98                    | 100    | 53               | 71            | 62  | 56        | 41.73    |     |
| 2.36                        | 3      | 4      | 96             | 56                    | 100    | 42               | 58            | 50  | 44        | 31.81    |     |
| 1.18                        | 3      | 1      | 87             | 46                    | 100    | 34               | 48            | 41  | 38        | 10.64    |     |
| 0.600                       | 2      | 1      | 56             | 33                    | 100    | 26               | 38            | 32  | 26        | 32.72    |     |
| 0.300                       | 2      | 1      | 38             | 26                    | 98     | 18               | 28            | 23  | 20        | 10.05    |     |
| 0.150                       | 2      | 1      | 1              | 26                    | 98     | 12               | 20            | 16  | 12        | 18.58    |     |
| 0.075                       | 1      | 1      | 1              | 9                     | 86     | 4                | 10            | 7   | 6         | 2.12     |     |
| Solution Bar                |        |        |                |                       |        |                  |               |     |           | 166.2308 |     |
| Proportion                  | 0.0000 | 0.4100 | 0.2200         | 0.3500                | 0.0200 | Total Proportion |               |     |           | 1.00     |     |
| Percent                     | 0.00   | 41.00  | 22.00          | 35.00                 | 2.00   | 0.00             | Total Percent |     |           |          | 100 |

Therefore, as per the gradation and as per the specified limits of MORTH the contents used in the mix have following proportions:

- 20 mm nominal aggregate size = 0%
- 10 mm nominal aggregate size = 41%
- Fine aggregate, sand = 22%
- 4.75 mm down & dust = 35%
- Filler, cement (53 grade) = 2%

Further, the samples are prepared with bitumen VG 10 binder and are further modified with the nano material Zycotherm. The binder content is changed with different percentages (5.5%, 6%, 6.5%) and the zycotherm percentage is also varied (0.1%, 0.125%, 0.15%) of the binder content.

In this study, we investigate the effect of a Nano-material with the trade name of zycotherm.

Zycotherm is a chemically reactive performance enhancing Cum Moisture Resistant additive to modify the aggregates for stronger adhesion with the Asphalt Binder and eliminate damage to the bitumen layers due to moisture ingress. Key benefits are detailed below:

- Eliminates stripping.
- Higher Marshall Stability
- Improved compaction densities with same compaction effort / lower passes
- Higher rut resistance
- Odor less, non –corrosive, non-flammable.
- Dosage - 0.05% to 0.1 % by wt. of asphalt binder
- Stable on storage for above 15 days and suitable for terminal blending.
- Eliminates stripping - Residual water in aggregate at lower mix temperature helps to promote reactivity with aggregate

**Mixing of Bitumen and Additive:** As according to its manufacturer company, the mixing dosage of zycotherm is 0.05 to 0.15 of weight percent of bitumen, we selected the mixing does of **0.1, 0.125, and 0.15** percent for manufacturing of bitumen with additive. We calculated specific gravity, air void, Marshall Resistance and Plastic Flow of samples after producing them.

*Results of Marshall test: Determination of density and void analysis*

**G1 = apparent specific gravity of coarse aggregates = 2.8**  
**G2 = apparent specific gravity of fine aggregates = 2.07**  
**G3 = apparent specific gravity of filler = 1.4**  
**G4 = apparent specific gravity of bituminous binder = 1.01**  
**W1 = % by wt. of coarse aggregates in total mix = 492 g**  
**W2 = % by wt. of fine aggregates in total mix = 264 g**  
**W3 = % by wt. of filler = 420 g**  
**W4 = % by wt. of bituminous binder in the total mix (66 g, 72 g, 78 g)**  
**Marshall Test: Determination of density and voids**

| Sample no. | Bitumen content,% | Zycotherm content,% | Height of sample, mm | Dia of sample, mm | Weight, g |          | Bulk Density, Gm | Theoretical density, Gt | Vv   | Vb   | VMA   | VFB   |
|------------|-------------------|---------------------|----------------------|-------------------|-----------|----------|------------------|-------------------------|------|------|-------|-------|
|            |                   |                     |                      |                   | In air    | In water |                  |                         |      |      |       |       |
| 1          | 5.5               | 0                   | 65.8                 | 101.72            | 1228      | 699      | 2.32             | 3.10                    | 3.10 | 7.91 | 11.01 | 68.58 |
| 2          |                   |                     | 65.3                 | 102.1             | 1226      | 697      |                  |                         |      |      |       |       |
| Average    |                   |                     | 65.55                | 101.91            | 1227      | 698      |                  |                         |      |      |       |       |
| 1          | 5.5               | 0.1                 | 62.44                | 104.46            | 1268      | 743      | 2.48             | 3.07                    | 4.40 | 7.93 | 11.70 | 66.50 |
| 2          |                   |                     | 61.02                | 101.62            | 1258      | 755      |                  |                         |      |      |       |       |
| Average    |                   |                     | 61.73                | 103.04            | 1263      | 749      |                  |                         |      |      |       |       |
| 1          | 5.5               | 0.125               | 62.7                 | 101.04            | 1268      | 757      | 2.51             | 3.20                    | 4.20 | 7.95 | 11.40 | 68.50 |
| 2          |                   |                     | 62.3                 | 103.06            | 1272      | 767      |                  |                         |      |      |       |       |
| Average    |                   |                     | 62.5                 | 102.05            | 1270      | 762      |                  |                         |      |      |       |       |
| 1          | 5.5               | 0.15                | 62.72                | 101.13            | 1288      | 765      | 2.51             | 3.30                    | 3.90 | 8.00 | 11.60 | 68.50 |
| 2          |                   |                     | 64.08                | 101.01            | 1276      | 777      |                  |                         |      |      |       |       |
| Average    |                   |                     | 63.4                 | 101.07            | 1282      | 771      |                  |                         |      |      |       |       |
| 1          | 6                 | 0                   | 64.3                 | 100.94            | 1288      | 766      | 2.35             | 3.2                     | 4.00 | 7.92 | 11.71 | 70.53 |
| 2          |                   |                     | 64.1                 | 101.01            | 1284      | 764      |                  |                         |      |      |       |       |
| Average    |                   |                     | 64.2                 | 100.97            | 1286      | 765      |                  |                         |      |      |       |       |
| 1          | 6                 | 0.1                 | 63.1                 | 100.85            | 1276      | 772      | 2.53             | 3.21                    | 4.50 | 7.93 | 11.92 | 69.21 |
| 2          |                   |                     | 62.88                | 101.34            | 1268      | 765      |                  |                         |      |      |       |       |
| Average    |                   |                     | 62.99                | 101.09            | 1272      | 768.5    |                  |                         |      |      |       |       |
| 1          | 6                 | 0.125               | 62.82                | 101.72            | 1272      | 770      | 2.54             | 3.57                    | 4.30 | 7.94 | 11.80 | 67.31 |
| 2          |                   |                     | 62.9                 | 101.39            | 1268      | 756      |                  |                         |      |      |       |       |
| Average    |                   |                     | 62.86                | 101.55            | 1270      | 763      |                  |                         |      |      |       |       |
| 1          | 6                 | 0.15                | 62.28                | 101.26            | 1274      | 772      | 2.55             | 3.78                    | 4.10 | 7.95 | 11.60 | 71.57 |
| 2          |                   |                     | 63.02                | 101.58            | 1268      | 769      |                  |                         |      |      |       |       |
| Average    |                   |                     | 62.65                | 101.42            | 1271      | 770.5    |                  |                         |      |      |       |       |

2. Result and Discussion

2.1 TEST RESULTS ON MODIFIED BINDER

| S NO. | CHARACTERISTICS                                   | PAVING GRADES REQUIREMENT (VG 10) | VG – 10            | OBSERVED VALUES AFTER ADDITION OF ZYCOTHERM |                    |                    |
|-------|---|-----------------------------------|--------------------|---|--------------------|--------------------|
|       |   |                                   |                    | VG10+0.1%                                   | VG10 +0.125%       | VG10+0.15%         |
| 1     | Penetration at 25 C,100 g, 50 s, 0.1 mm, Min      | 80                                | 70                 | 68  | 67                 | 65                 |
| 2     | Absolute viscosity at 60 C , Poises               | 800-1200                          | 1072.3             | 1092.3                                      | 1100.7             | 1109.8             |
| 3     | Kinematic viscosity at 135 C, cSt, Min            | 250                               | 265.27             | 270.3                                       | 273.2              | 283.5              |
| 4     | Flash point(open cup ), C, Min                    | 220                               | 240                | 235   | 230                | 231                |
| 5     | Softening point, C, Min                           | 40                                | 48                 | 49  | 51                 | 53                 |
| 6     | Specific gravity                                  | 0.97-1.02                         | 1.01               | 1.01  | 1.031              | 1.029              |
| 7     | Test on residue from rolling thin film oven test: |                                   |                    |   |                    |                    |
|       | a) Viscosity ratio at 60 C, Max                   | 4.0<br>75                         | 1.029<br>Above 100 | 1.02<br>Above 100                           | 1.031<br>Above 100 | 1.041<br>Above 100 |
|       | b) Ductility at 25 C, cm, Min                     |                                   |                    |   |                    |                    |

2.2 TEST RESULTS OF MODIFIED DESIGN MIX SAMPLES

As per **MORTH** the requirements and the observed values for the dense bituminous concrete mix are for **5.5% bitumen content** and **0% , 0.1% , 0.125 and 0.15% zycotherm content** :

| Properties                         | Viscosity grading paving bitumen  | Test method         | OBSERVED VALUES AFTER ADDITION OF ZYCOTHERM |           |             |             |
|------------------------------------|-----------------------------------|---------------------|---|-----------|-------------|-------------|
|                                    |                                   |                     | 0%  | 0.1%      | 0.125%      | 0.15%       |
| Compaction level                   | 75 blows on each face of specimen |                     | 0%  | 0.1%      | 0.125%      | 0.15%       |
| Minimum stability (KN at 600 C)    | 9.0                               | AASHTO T245         | 12.00                                       | 10.19     | 11.20       | 12.20       |
| Marshall flow (mm)                 | 2 – 4                             | AASHTO T245         | 3.0   | 3.10      | 3.30        | 3.10        |
| Marshall quotient (stability/flow) | 2 – 5                             | MS-2 and ASTM D2041 | 4.03  | 3.28      | 3.39        | 3.93        |
| % air voids Vv                     | 3 – 5                             |                     | 3.80  | 4.40      | 4.20        | 3.90        |
| % Voids filled with bitumen (VFB)  | 65 – 75                           |                     | 68.58                                       | 66.50     | 65.30       | 68.50       |
| Coating of aggregate particle      | 95% minimum                       | IS : 6241           | 98%   | 99% above | Almost 100% | Almost 100% |
| % Voids in mineral aggregate (VMA) | For Vv 3% = 11                    |                     | 11.10                                       | 11.70     | 11.40       | 11.60       |
|                                    | For Vv 4% = 12                    |                     |   |           |             |             |
|                                    | For Vv 5% = 12                    |                     |   |           |             |             |

As per **MORTH** the requirements and the observed values for the dense bituminous concrete mix are for **6% bitumen content** and **0% , 0.1% , 0.125 and 0.15% zycotherm content** :

| Properties                         | Viscosity grading paving bitumen  | Test method         | OBSERVED VALUES AFTER ADDITION OF ZYCOTHERM |           |             |             |
|------------------------------------|-----------------------------------|---------------------|---|-----------|-------------|-------------|
|                                    |                                   |                     | 0%  | 0.1%      | 0.125%      | 0.15%       |
| Compaction level                   | 75 blows on each face of specimen |                     | 0%  | 0.1%      | 0.125%      | 0.15%       |
| Minimum stability (KN at 600 C)    | 9.0                               | AASHTO T245         | 13.00                                       | 12.03     | 12.10       | 13.10       |
| Marshall flow (mm)                 | 2 – 4                             | AASHTO T245         | 3.70  | 3.69      | 3.60        | 3.50        |
| Marshall quotient (stability/flow) | 2 – 5                             | MS-2 and ASTM D2041 | 3.56  | 3.99      | 3.10        | 3.74        |
| % air voids Vv                     | 3 – 5                             |                     | 4.0   | 4.50      | 4.30        | 4.10        |
| % Voids filled with bitumen (VFB)  | 65 – 75                           |                     |   |           |             |             |
| Coating of aggregate particle      | 95% minimum                       | IS : 6241           | 98%   | 99% above | Almost 100% | Almost 100% |
| % Voids in mineral aggregate (VMA) | For Vv 3% = 11                    |                     | 11.71                                       | 11.92     | 11.80       | 11.60       |
|                                    | For Vv 4% = 12                    |                     |   |           |             |             |
|                                    | For Vv 5% = 12                    |                     |   |           |             |             |

As per **MORTH** the requirements and the observed values for the dense bituminous concrete mix are for **6.5% bitumen content** and **0% , 0.1% , 0.125 and 0.15% zycotherm content** :

| Properties                         | Viscosity grading paving bitumen  | Test method         | OBSERVED VALUES AFTER ADDITION OF ZYCOTHERM |           |             |             |
|------------------------------------|-----------------------------------|---------------------|---|-----------|-------------|-------------|
|                                    |                                   |                     | 0%  | 0.1%      | 0.125%      | 0.15%       |
| Compaction level                   | 75 blows on each face of specimen |                     | 0%  | 0.1%      | 0.125%      | 0.15%       |
| Minimum stability (KN at 600 C)    | 9.0                               | AASHTO T245         | 12.6  | 11.10     | 11.70       | 12.70       |
| Marshall flow (mm)                 | 2 – 4                             | AASHTO T245         | 3.90  | 3.95      | 3.50        | 3.70        |
| Marshall quotient (stability/flow) | 2 – 5                             | MS-2 and ASTM D2041 | 3.30  | 2.81      | 3.34        | 3.43        |
| % air voids Vv                     | 3 – 5                             |                     | 4.20  | 4.60      | 4.40        | 4.10        |
| % Voids filled with bitumen (VFB)  | 65 – 75                           |                     | 72.34                                       | 71.01     | 69.86       | 73.01       |
| Coating of aggregate particle      | 95% minimum                       | IS : 6241           | 98%   | Above 99% | Almost 100% | Almost 100% |
| % Voids in mineral aggregate (VMA) | For Vv 3% = 11                    |                     | 11.90                                       | 11.98     | 11.73       | 11.70       |
|                                    | For Vv 4% = 12                    |                     |   |           |             |             |
|                                    | For Vv 5% = 12                    |                     |   |           |             |             |

### 3 SUMMARY AND CONCLUSIONS

Zycotherm should be stored between 5 - 45° C (41 - 113° F) in a shaded, dry area away from sunlight, heat, ignition, sparks, rain, and standing water. The container lid should be securely fastened every time it is used. Shelf live is 24 months.

Zycotherm due to its nature, exert specific dimension properties. As a result, it exhibits specific characteristics, qualities and unique features compared to commonly used materials, making likewise feasible their integration as additives in

asphalt pavements. Ordinary pavement materials can hardly meet the operational requirements for present and future highways as well as pavement construction technology.

Consequently, pavement materials of enhanced quality, increased safety, higher reliability and more environmental friendly features, are in high demand. The dispersion of zycotherm within asphalt materials may considerably enhance certain properties of asphalt constituents, e.g., visco-elasticity, high temperature effects, resistance to aging, fatigue and moisture). The zycotherm applied in asphalt pavement engineering with their specific properties are categorized in the next points:

1. The physical properties were conducted on the aggregates and the binder used in the present studies satisfies the requirements as per the MORT&H specifications.
2. Increasing percentage of additive dosage to rate of Marshall Properties also increases and satisfies the MORT&H specifications.
3. The Marshall properties of HMA in the present studies satisfy the MORT&H specifications.
4. The optimum bitumen content was found to be 6% for HMA mix at 160<sup>0</sup>c temperature.
5. The maximum stability for 60/70 grade bitumen is achieved at 160<sup>0</sup>c temperature with the additive dosage rate of 0.15% of Zycotherm by the weight of binder.
6. The addition of additive of zycotherm improves bulk density of the mix. The percentage air voids in the mix were found to decrease with the increase of HMA additive and 0.15% of zycotherm at 160<sup>0</sup>c was lowest when compared to the conventional mix.
7. Residual water in aggregate at lower temperature helps to promote reactivity with the aggregate and can withstand boil tests lasting over six hours with an over 95% retained coating.
8. Captures sticky asphaltenes in nano cages of Zycotherm for improved free flow and reduced stickiness to trucks or paver and compaction rollers.
9. Wets & spreads even better at lower bitumen content to give a blacker looking mix
10. Captures all odorous compounds in nano cages of the Zycotherm Lowers mixing temperature by 95° C, saves fuel by 20-25% OR Helps in longer hauls OR Allows paving in cold conditions 32 - 41°F.

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