Experimental studies to characterize gradation segregation of asphalt mixes

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Abstract. Gradation segregation can be described as the non-homogeneity of the asphalt mix which includes coarse aggregates and fine aggregates which may tend to segregate during the process of crushing, stockpiling, mixing in hot mix plant, transportation and paving practices. There are various methods to determine the gradation segregation such as visual judgment, sand-paving test, digital image processing method, nuclear density meter measurement, ground penetrating radar, infrared thermal imaging etc., these detection methods are used to determine the segregation only on the paved asphalt mix but these methods cannot be used to evaluate the extent of segregation occurred before paving the asphalt mix. Since many researchers have carried out work on gradation segregation, still enormous work has to be carried out to determine the gradation segregation before paving the asphalt mix. Hence, in the present study, a test equipment is designed and fabricated to determine the gradation segregation that can be used in the laboratory. Using the test equipment and an index ∆∑Pi the extent of gradation segregation has been determined for various asphalt mixes such as Bituminous Concrete (BC) grading 1 and 2, Dense Bituminous Macadam (DBM) grading-1, Cold mix for Bituminous Concrete grading - 2 and Open Graded Friction Course (OGFC) mixes as per MORTH and ASTM are investigated. The results indicated that the extent of gradation segregation is severe for DBM grading-1, moderate segregation for BC grading -2, and no or slight segregation for BC grading-2 cold. As the maximum nominal aggregates sizes increase segregation levels also increases and as the coarse aggregate sizes increases in the gradation of the mix the amount of segregation also increased and get segregated under gravity forces.

1. Introduction

The problem of segregation in the asphalt mix has been widely discussed in the literature. Till now numerous methods have been presented for the determination of segregation in the asphalt mix after paving. Segregation leads to the early-stage distress of the pavement such as cracking, rutting, raveling, potholes and stripping. This distress will affect the performance, serviceability and structural capacity of the pavement [2]. The next most common distress in segregated areas on pavement is a loss of riding quality and cracking along the longitudinal profile of the pavement due to vehicles moving along the same wheel path and also fatigue cracks on the pavement are the indication of distress in segregated parts of pavement [14].

Distresses on the pavement surface will decrease the riding quality for the road user and increases the vehicle operating cost (VOC) of the road users. Which indirectly affects the economy of the individuals and country. And also, the construction of the pavements includes lots of money which will affect the states or countries economy. Therefore, good quality of pavement is to be constructed for the betterment of the individuals and the country. In this point of view, the present study is carried out.

There are two different types of segregation in the hot asphalt mix. They are Temperature segregation and Gradation segregation. Temperature segregation deals with asphalt mix cooling areas during production, transportation, and construction [3]. Gradation segregation can be described as the non-
homogeneity of the asphalt mix which includes coarse aggregates and fine aggregates which may tend to segregate during the process of crushing and stockpiling, mixing in hot mix plant, transportation and paving practices of asphalt mix [1]. But in this study, we are concentrating on the determination of gradation segregation before paving.

Coarse aggregate segregation occurs when gradation includes more quantity of coarse aggregates and less quantity of fine aggregates and can be characterized by higher air voids, low density, rough surface texture, less asphalt content, rutting, and fatigue failure and also results in moisture susceptibility due to higher air voids. Fine aggregate segregation occurs when gradation includes more quantity of fine aggregates and less quantity of coarse aggregate and can be characterized by lesser air voids, low density, smooth surface texture and results in rutting.

There are various methods to determine the gradation segregation such as visual judgment, sand-paving test, digital image processing method, nuclear density meter measurement, ground penetrating radar, infrared thermal imaging etc., but these identification methods can detect the segregation only after the asphalt mix is paved. And can be used to evaluate the segregation of the asphalt mix but cannot be used to evaluate the extent of segregation in the asphalt mix [1].

Therefore, in the present study the simulation of gradation segregation during the process of production, transportation and construction of the asphalt mix is studied by using the test equipment that can be used in the laboratory to identify gradation segregation of asphalt mix is fabricated and gradation segregation is determined for Bituminous Concrete (BC) grading 1 and 2, Dense Bituminous Macadam (DBM) grading-1, Cold mix for Bituminous Concrete grading - 2 and Open Graded Friction Course (OGFC) mixes as per MoRTH and ASTM.

2. Materials and methodology

An experimental program was designed to study the gradation segregation of asphalt mixes and to evaluate the extent of gradation segregation of different asphalt mixes. For this purpose, laboratory test equipment was fabricated and tests were conducted on different asphalt mixes using the fabricated test equipment. The gradation segregation for Bituminous Concrete (BC) grading 1 and 2, Dense Bituminous Macadam (DBM) grading-1, Cold mix for Bituminous Concrete grading - 2 and Open Graded Friction Course (OGFC) mixes as per MORTH was interpreted from each test and analyzed.

2.1. Design and fabrication of gradation segregation test equipment

Gradation segregation test equipment was designed based on the principle of earlier equipment [1]. The equipment was illustrated in a figure and dimensions were not specified. Hence with suitable dimensions, self-designed equipment was fabricated.

The test equipment consists of:
- Feeding Hopper
- Tilted Baffle Plate
- Two Storage Hopper

Dimensions of the feeding hopper were obtained from Indian Standard Code for Specification for Compacting Factor Apparatus IS 5515-1983 (Reaffirmed 2004). Feeding hopper is fabricated in such a way that it can be movable horizontally on the frame with nut and bolt assembly. The width of the baffle plated was assumed 3 times the bottom internal diameter of the feeding hopper. And the length was assumed as 5 times the bottom internal diameter of the feeding hopper. The baffle plate is fabricated in such a way that it can be tilted from 38 to 90 vertically with nut and bolt assembly. In this study, the gradient was fixed at 45.
2.2. Test procedure

After the mix design and optimum binder content are obtained, a mix of about 6 – 8 kg of the asphalt mix is mixed according to the mix proportion, optimum binder content and mixing temperature. The inner wall of the feeding hopper and the baffle plate are waxed by oil to prevent the asphalt mix adhering to it. The asphalt mix is added or poured into the feeding hopper at the temperature of 130-140 °C. The closet valve of the feeding hopper is opened and the mix will fall on the baffle plate and
correspondingly to the two storage hoppers. The asphalt mix in the front and rear storage hoppers are collected and bitumen extraction is performed. The aggregates after bitumen extraction in the front and rear hoppers are sieved according to the graduation of the mix.

2.3. Evaluate the extent of gradation segregation
In order to determine and classify the gradation segregation level in the asphalt mix, the aggregates in the front and rear hoppers are sieved according to the gradation after bitumen extraction is performed. The front and rear hopper aggregates are sieved according to the gradation and the summation of passing rate difference ($\Delta \sum P_i$) of the front and rear hopper is calculated and used as an index to determine the extent of the gradation segregation of the asphalt mix [1].

Gradation segregation of the asphalt mix is classified into three different levels:

- When ($\Delta \sum P_i$) is in the range of 0-100% the segregation is classified as no segregation or slight segregation.
- When ($\Delta \sum P_i$) is in the range of 100-200% the segregation is classified as moderate segregation.
- When ($\Delta \sum P_i$) is greater than 200% the segregation is severe segregation.%.

2.4. Characteristics of materials used
2.4.1. Aggregates
Aggregate tests were conducted for physical requirements specified in Specification as per MoRTH Table 500-16 for Bituminous Concrete (BC) grading 1, 2, Cold mix of BC grading 2 and Open Graded Friction Course (OGFC) and the test results also conform for Dense Bituminous Macadam MoRTH Table 500-8. The test results are as shown in the table below.

| Table 1. Physical properties of aggregates |
|-----------------------------------------|
| Test description | Results |
| Specific gravity | 2.64 |
| Water absorption (%) | 0.25 |
| Impact value (%) | 15.7 |
| Combined flakiness and elongation index (%) | 23.2 |
| Los Angeles abrasion value (%) | 28.3 |

2.4.2 Binder
Binder used for the study is paving grade bitumen VG-30. The paving bitumen binder tests were conducted for physical requirements specified in Specification as per IS 73: 2013.

| Table 2. Physical properties of binder |
|--------------------------------------|
| Test | Method of Test | Results | Specification as per IS:73-2013 |
| Penetration (mm) @ 25°C | IS:1203 | 65 | 45 |
| Softening Point (°C), minimum | IS:1205 | 52.1 | 47 |
| Flash Point (°C), minimum | IS:1488 | 270 | 220 |
| Specific Gravity | 1.02 | 0.97-1.02 |

2.4.3 Emulsion
Binder used for the cold mix in the study is medium setting grade cationic emulsion obtained from Hindustan Colas Pvt. Limited, Mangalore. The medium setting grade cationic emulsion tests were conducted for physical requirements specified in Specification as per IS 8887: 2004.
Table 3. Physical properties of medium setting cationic emulsion

| Test                                                                 | Method of Test | Results | Specification as per IS:8887-2004 |
|----------------------------------------------------------------------|----------------|---------|-----------------------------------|
| Residue on 600 microns IS Sieve, Percent by mass, maximum           | IS:8887        | 0.017%  | 0.05%                             |
| Viscosity by sayboltfurol viscometer, at 50 C, seconds: Coating ability and water resistance: | IS:3317        | 159     | 50-300                            |
| 1) Coating, dry aggregate                                          |                |         | Good                              |
| 2) Coating, after spraying                                         | IS:8887        | Fair    | Good                              |
| 3) Coating, wet aggregate                                          |                |         | Fair                              |
| 4) Coating, after spraying                                         |                |         | Fair                              |
| Miscibility with water Tests on residue:                           | IS:8887        | No Coagulation | No Coagulation                     |
| 1) Residue by evaporation, percent, Minimum                        | IS:8887        | 67%     | 65%                               |
| 2) Penetration25°C/ 100g/ 5 sec, mm                                 | IS:1203        | 87      | 60-150                            |

2.4.4. Mix design of asphalt mixes
Proportioning of the different sizes of aggregates is carried for obtaining a proper blend of consistency mix and also to satisfy the required gradation as per MoRTH specifications for BC grading 1 and 2, DBM grading 1, Cold mix for BC grading 2 as per IRC: SP: 100-2014 and ASTM D7064/D7064M – 08 (Reapproved 2013) specifications for OGFC. Preparation of mix and obtaining optimum binder content for each asphalt mixes are determined by Marshall Method for BC grading-1 and 2, DBM grading-1, OGFC and BC grading-2 Cold mix.

Table 4. Optimum Binder Content for Asphalt Mixes

| Asphalt Mixes       | Optimum Binder Content (%) |
|---------------------|-----------------------------|
| BC Grading-1        | 5.3                         |
| BC Grading-2        | 5.55                        |
| DBM Grading-1       | 4                           |
| OGFC                | 6                           |
| BC Grading-2 Cold Mix | 7.75                        |

3. Results and discussion
3.1. Gradation segregation test results of asphalt mixes
After the mix design and optimum binder content are obtained, a mix of about 6 – 8 kg of the asphalt mix is mixed according to the mix proportion, optimum binder content and mixing temperature. And the gradation segregation test, bitumen extraction test and extent of segregation is conducted. Three tests were conducted per mix and the test results are computed. The average of the three test results tabulated.

The results for BC grading-1 is shown below likewise for the other mixes are the results are obtained and the results are discussed.

Table 5. Gradation segregation for BC grading-1

| IS Sieve Size (mm) | Rear hopper Percentage passing | Front hopper Percentage passing | Difference in front and rear storage hoppers |
|--------------------|--------------------------------|--------------------------------|---------------------------------------------|
| 26.5               | 100.00                         | 100.00                         | 0.00                                        |
| 19                 | 98.74                          | 86.74                          | 12.00                                       |
| 13.2               | 93.51                          | 65.17                          | 28.34                                       |
| 9.5                | 84.61                          | 52.78                          | 31.83                                       |
| IS Sieve Size (mm) | Rear hopper Percentage passing | Front hopper Percentage passing | Difference in front and rear storage hoppers |
|-------------------|--------------------------------|--------------------------------|-----------------------------------------------|
| 4.75              | 57.34                          | 31.92                          | 25.42                                         |
| 2.36              | 34.31                          | 20.25                          | 14.06                                         |
| 1.18              | 16.99                          | 11.58                          | 5.41                                          |
| 0.6               | 11.44                          | 8.23                           | 3.21                                          |
| 0.3               | 4.21                           | 3.34                           | 0.87                                          |
| 0.15              | 1.98                           | 1.68                           | 0.30                                          |
| 0.075             | 0.00                           | 0.00                           | 0.00                                          |
| **Total**         | **503.20**                     | **381.72**                     | **121.45**                                    |

**Table 6. Gradation segregation for BC grading-2**

| IS Sieve Size (mm) | Rear hopper Percentage passing | Front hopper Percentage passing | Difference in front and rear storage hoppers |
|-------------------|--------------------------------|--------------------------------|-----------------------------------------------|
| 19                | 100.00                         | 100.00                         | 0.00                                          |
| 13.2              | 93.76                          | 82.82                          | 10.94                                         |
| 9.5               | 85.22                          | 65.57                          | 19.65                                         |
| 4.75              | 54.88                          | 33.78                          | 21.10                                         |
| 2.36              | 39.34                          | 24.10                          | 15.24                                         |
| 1.18              | 23.17                          | 16.49                          | 6.67                                          |
| 0.6               | 15.55                          | 11.85                          | 3.70                                          |
| 0.3               | 6.31                           | 5.01                           | 1.30                                          |
| 0.15              | 3.34                           | 2.56                           | 0.77                                          |
| 0.075             | 0.00                           | 0.00                           | 0.00                                          |
| **Total**         | **421.61**                     | **342.22**                     | **79.39**                                     |

**Table 7. Gradation segregation for DBM grading-1**

| IS Sieve Size (mm) | Rear hopper Percentage passing | Front hopper Percentage passing | Difference in front and rear storage hoppers |
|-------------------|--------------------------------|--------------------------------|-----------------------------------------------|
| 45                | 100.00                         | 100.00                         | 0.00                                          |
| 37.5              | 100.00                         | 89.19                          | 10.80                                         |
| 26.5              | 100.00                         | 67.51                          | 32.48                                         |
| 13.2              | 92.78                          | 46.73                          | 46.05                                         |
| 4.75              | 76.96                          | 22.88                          | 54.08                                         |
| 2.36              | 59.67                          | 8.71                           | 50.96                                         |
| 0.3               | 15.60                          | 2.39                           | 13.21                                         |
| 0.075             | 0.00                           | 0.00                           | 0.00                                          |
| **Total**         | **545.041**                    | **337.439**                    | **207.60**                                    |

**Table 8. Gradation segregation for OGFC**

| IS Sieve Size (mm) | Rear hopper Percentage passing | Front hopper Percentage passing | Difference in front and rear storage hoppers |
|-------------------|--------------------------------|--------------------------------|-----------------------------------------------|
| 19                | 100.00                         | 100.00                         | 0.00                                          |
| 12.5              | 97.63                          | 91.11                          | 6.52                                          |
| 9.5               | 66.01                          | 50.15                          | 15.85                                         |
| 4.75              | 23.35                          | 12.31                          | 11.03                                         |
| 2.36              | 6.72                           | 4.39                           | 2.33                                          |
| 0.075             | 0.00                           | 0.00                           | 0.00                                          |
| **Total**         | **293.72**                     | **257.97**                     | **35.74**                                     |
Table 9. Gradation segregation for BC Grading-2 Cold Mix

| IS Sieve Size (mm) | Rear hopper Percentage passing | Front hopper Percentage passing | Difference in front and rear storage hoppers |
|-------------------|--------------------------------|--------------------------------|---------------------------------------------|
| 19                | 100.00                         | 100.00                         | 0.00                                        |
| 13.2              | 96.71                          | 84.41                          | 12.29                                       |
| 9.5               | 85.61                          | 66.26                          | 19.34                                       |
| 4.75              | 63.13                          | 43.87                          | 19.26                                       |
| 2.36              | 37.86                          | 26.61                          | 11.24                                       |
| 1.18              | 21.09                          | 15.57                          | 5.51                                        |
| 0.6               | 15.11                          | 10.82                          | 4.28                                        |
| 0.3               | 6.85                           | 3.94                           | 2.91                                        |
| 0.15              | 3.63                           | 1.69                           | 1.94                                        |
| 0.075             | 0.00                           | 0.00                           | 0.00                                        |
| Total             | 430.02                         | 353.21                         | 76.81                                       |

Graphs of sieve size versus $\Delta \sum \Pi_i$ are plotted for all asphalt mixes to study the behaviour of aggregates sizes on the segregation. Graph sieve size versus $\Delta \sum \Pi_i$ shows a parabolic trend for all the mixes tested with a peak sieve size of coarse aggregate and the corresponding $\Delta \sum \Pi_i$ is as follows.

Table 10. Coarse aggregates particles contributing maximum to segregation

| Asphalt Mixes       | Sieve size | Corresponding sieve $\Delta \sum \Pi_i$ |
|---------------------|------------|----------------------------------------|
| BC Grading-1        | 9.5 mm     | 31.8%                                  |
| BC Grading-2        | 4.75 mm    | 21.1%                                  |
| DBM Grading-1       | 4.75 mm    | 54%                                    |
| OGFC                | 9.5 mm     | 15.8%                                  |
| BC Grading-2 Cold Mix | 9.5 mm | 19.3%                                  |

It is observed that coarse aggregates are the particles contributing maximum to segregation because coarse aggregates weigh more mass per particle and get segregated. Coarse aggregate sizes having maximum $\Delta \sum \Pi_i$ that contributes to segregation than other sizes of aggregates in the gradation are as follows.

Table 11. Coarse Aggregate Sizes having Maximum $\Delta \sum \Pi_i$

| Asphalt mixes       | Coarse aggregate size range contributing to segregation |
|---------------------|--------------------------------------------------------|
| BC Grading-1        | 2.36 mm to 19 mm                                       |
| BC Grading-2        | 2.36 mm to 13.2 mm                                     |
| DBM Grading-1       | 2.36 mm to 26.5 mm                                     |
| OGFC                | 4.75 mm to 9.5 mm                                      |
| BC Grading-2 Cold Mix | 2.36 mm to 13.2 mm                                  |

As the range of coarse aggregate sizes increases in the gradation, segregation is also increasing. Because higher size coarse aggregate weighs more mass per particle and get segregated under gravity forces.

The extent of gradation segregation is severe for DBM grading-1 because the maximum nominal aggregate size is 37.5 mm which is greater than the other mixes compared in the study. The BC grading-1 has shown moderate gradation segregation which has a maximum nominal size of the aggregate 19 mm. The BC grading-2, OGFC and BC grading-2 cold mix has shown slight or no gradation segregation whose maximum nominal size of the aggregate less than 13.2.
The evaluation of the extent of gradation segregation levels of the asphalt mixes are as follows:

| Asphalt mixes | ∆ΣPi     | Maximum nominal aggregate size (mm) | Optimum Binder Content | Gradation Segregation Levels          |
|---------------|----------|-------------------------------------|------------------------|-------------------------------------|
| DBM Grading-1 | 207.6%   | 37.5                                | 4%                     | Severe Segregation (>200%)          |
| BC Grading-1  | 121.4%   | 19                                  | 5.3%                   | Moderate segregation (100-200%)     |
| BC Grading-2  | 79.3%    | 13.2                                | 5.5%                   | Slight or No Segregation (0-100%)   |
| BC Grading-2  | 76.8%    | 13.2                                | 7.7%                   | Slight or No Segregation (0-100%)   |
| OGFC          | 35.7%    | 12.5                                | 6%                     | Slight or No Segregation (0-100%)   |

It is observed that as the maximum nominal aggregates sizes increases the gradation segregation levels are also increasing because higher size coarse aggregate weighs more mass per particle and get segregated under gravity forces. And also, as the asphalt content decreases, the gradation segregation levels are increasing, because low asphalt content results in low film thickness to hold the aggregates particles together and gets segregated.

4. Conclusion
   1. Fabricated equipment produced identical results to that of previous studies on gradation segregation. Hence the fabricated equipment can be used to determine the segregation.
   2. Gradation segregation has occurred for all the mixes as the summation of passing rate difference between the front and rear hopper exist and the asphalt mix have undergone segregation.
   3. The extent of gradation segregation is severe for DBM grading-1 as the maximum nominal aggregate size is 37.5 mm which is greater than the other mixes compared in the study. The BC grading-1 has shown moderate gradation segregation which has a maximum nominal size of the aggregate 19 mm. The BC grading-2, OGFC and BC grading-2 cold mix has shown slight or no gradation segregation whose maximum nominal size of the aggregate less than 13.2 mm.
   4. As the maximum nominal aggregate sizes increases, the gradation segregation levels are also increasing because higher size coarse aggregate weigh more mass per particle and get segregated under gravity forces.
   5. As the asphalt content decreases, the gradation segregation levels are increasing, because low asphalt content results in low film thickness to hold the aggregates particles together and gets segregated.

Acknowledgments
This project was supported finically by Technical Education Quality Improvement Programme of Government of India (TEQIP) Phase-III.

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