Laboratory Evaluation of Engineering and Strength Properties for Semi Rigid Mixtures

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Abstract. Semi rigid mixture is a unique type of mixture in recent years, which has two components: Open graded bituminous mix and cement mortar grout. In this study, engineering and strength properties of semi rigid mixtures with three selected gradations are investigated. The flowability, compressive strength and flexural strength are identified to measure the optimum cement mortar grout. Meanwhile for Open graded bituminous mix, volumetric analysis, drain down and cantabro abrasion loss tests are carried out for selected gradations by varying binder content to obtain optimum mixture. Further the compressive strength, flexural strength, stability, tensile strength and durability tests are evaluated for the selected gradations of optimised Semi Rigid mixtures. The results showed that cement mortar grout containing cement to M-Sand ratio of 1:1, water-cement ratio of 0.35 with super plasticizer (polycarboxylic ether polymer) dosage of 0.45% resulted in desired flow of 12 seconds, compressive strength and flexural strength of 27 MPa and 3.5 MPa respectively. The optimum binder contents of Open graded bituminous mix for the selected gradations are found to be in the range of 4.5-5.0%. Furthermore the obtained 4.5% binder content in Semi Rigid mixture have higher engineering and strength properties compared to 5.0% binder content.

1. Introduction
Over the past decades due to urbanization heavy trucks have increased enormously in the total traffic volume in developing countries like India where more than 90 percent of roads are bituminous pavement, demanding stronger and long lasting pavements. Bituminous pavements are considered for their satisfactory performance against traffic loads and also high resistance to skidding, good serviceability and riding quality, are used as highways [1]. On the other hand it suffered from major distresses like rutting, moisture damage and cracking due to high traffic volumes, overloading and variation in climatic condition. The disadvantages of bituminous pavement can be overcome by concrete pavements but initial cost is high, requires skills for construction and maintenance and also due to joints in concrete pavements riding quality is poor as well as the noise generated by the joints, the differential expansion/contraction needs to be accommodated [1]. Thus, a new technology of pavement need to be arise to overcome these distresses. One such type of pavement is Semi Rigid mixture, which is a reliable, joints free pavement, highly load carrying capacity, longer service life, easy to construct and repair and desirably having the nature of both rigidity and flexibility, moreover, offers riding quality and satisfactory serviceability. It has been adopted to furnish a durable and water proof surface for the
heavily loaded areas such as gas stations, bus terminal, airport runways, traffic intersection, parking lots and the like. This new type of pavement has prospects to be designed as a high performance pavement because it integrates the advantages of both rigid and flexible pavement, which appears to be a promising approach but less researched.

2. Background
In the 1960s, France introduced a new technology for pavement surface similar to Semi Rigid mixes known as ‘Resin Modified Pavement’ and in USA it was applied in 1987 [2]. Later, Semi rigid mixes technology was implemented in various countries like France, USA, Germany, Japan, Spain, Portugal, Sweden, Norway, Finland, Saudi Arabia, Great Britain, China, Denmark, Malaysia, South Africa and Austria had been used in bus stations, parking areas, intersections, warehouses, roads, aprons, etc. However in UK officially there is no BSEN (British Standards, Europe) specification on Semi rigid mixes yet. But ADEPT (Association of Directors of Environment, Economy, Planning and Transport) UK has developed a code of practice for grouted Macadam which is approved by the Highways Authorities Product Approval Scheme (HAPAS) in 2006 [3]. This technology was implemented by an organization called CIP Joint less Surfacing, primarily in Harbors, Airports, Warehouse Distributions, Bus-Depot Stations, Manufacturing-Production areas etc. In European countries like Denmark, Netherlands, Sweden etc. Semi Rigid mixes technology has been extensively used. The Copenhagen Airport, Denmark already laid approximately 3 lac m2. M/S BREMAT, Rosmalen, Netherlands carried out the execution and maintenance of this technology in Roundabouts, Intersections and Signals. Stockholm, Sweden implemented at different Bus stops and Bus-Depot stations, to bear the static loads and to diminish the chances of wearing and tearing. In USA, this technology incorporated in Army bases, Air force Stations and Airports. For durable surface, fuel damage resistant surface and heavily trafficked at two signalized intersections investigation was carried on McCord Air force Base, Washington and Logan International Airport, Malmstrom Air Force base, Montana and Mississippi Department of Transportation. In the Asian countries, this technology has been widely implemented in Malaysia, China, Japan, Saudi Arabia etc. Kualalampur City Council, Malaysia has implemented and maintained this technology since 2001 in heavily trafficked surface and Bus Lanes in the city area. In China, Ministry of Construction of Chinese Technologies had executed several projects in late 20th Century. In India, this technology has been still in research stage. The performance studies on this technology is carried out by CSIR-CRRI, New Delhi, National laboratory at Chennai and IIT Kharagpur, West Bengal. The Surat Municipal Corporation in collaboration with Sardar Vallabhbhai National Institute of Technology, Surat, Gujarat laid on two test sections in the city of Surat, of 100m length each for resurfacing the pavement [4].

3. Materials
The materials incorporated for the present study includes Conventional aggregates, Bitumen, Construction & Demolition waste aggregates, Fibers (Sugarcane fibers), Cement, M Sand and Super plasticizer.

3.1 Aggregate
The aggregates used in this investigation are procured from quarry near Bidadi, Bengaluru. Table 3.1 gives the Summary of aggregates physical properties.
Table 3.1: Summary of aggregates physical properties

| Tests                              | Result Obtained | Standard Specification | As Per Code                |
|------------------------------------|-----------------|------------------------|---------------------------|
| Aggregate Impact (%)               | 19              | Max24                  | IS: 2386-1963(Part 4)     |
| Los Angeles Abrasion (%)           | 20.76           | Max30                  | IS: 2386-1963(Part 5)     |
| Flakiness and Elongation (%)       | 25.12           | Max30                  | IS: 2386-1963(Part 1)     |
| Water Absorption (%)               | 0.2             | Max2.0                 | IS: 2386-1963(Part 3)     |

Aggregate Specific gravity

| Sieve size, mm | Specific gravity |                       |
|----------------|------------------|-----------------------|
| 19/12.5        | 2.88             |                       |
| 12.5/9.5       | 2.87             | IS: 2386-1963(Part 3) |
| 9.5/4.75       | 2.87             |                       |
| 4.75/2.36      | 2.88             |                       |
| 2.36/0.075     | 2.81             |                       |

3.2 Bitumen

VG 30 grade bitumen used in this study and the basic tests were carried out according to IS 73 2013. Table 3.2 shows summary of VG-30 bitumen physical properties, the mixing and compaction temperature for this bitumen is 152°C-156°C and 138°C-142°C respectively. The temperatures corresponding to viscosity ranges of 0.17Pa-sec and 0.27Pa-sec were plotted in the graph and the resulting temperatures are chosen for compacting and mixing.

3.3 Cement

In this investigation Ultratech 53 grade cement were used. Table 3.3 shows summary of 53 grade cement properties.

3.4 M-Sand

The M-Sand was procured from a plant near Bidadi, Bengaluru. The sand should pass 0.6mm size and retained 0.075mm so that the grout will enter into the air voids easily. Table 3.4 shown the summary of M sand properties of as per IS 1542.

Table 3.2: Summary of VG-30 bitumen physical properties

| Tests                              | Result Obtained | Standard Specification | Standard test method |
|------------------------------------|-----------------|------------------------|----------------------|
| Penetration@ 25°C, 0.1 mm          | 58              | 45 minimum             | IS:1203              |
| Ductility @ 25°C, cm               | 91              | 40 minimum             | IS:1208              |
| Specific Gravity                   | 0.98            | 0.97-1.02              | IS:1202              |
| Softening Point Test, °C           | 50.75           | 47 minimum             | IS:1205              |
| Kinematic Viscosity, cSt           | 368             | 350 minimum            | IS:1206 – Part 3     |
### Table 3.3: Summary of 53 grade cement Properties

| Properties evaluated       | Obtained Value | Standard Specification |
|----------------------------|----------------|------------------------|
| Fineness, m²/kg            | 260            | 225                    |
| Standard Consistency,%     | 33             | --                     |
| Initial Setting Time(min)  | 80             | 30                     |
| Final Setting Time(min)    | 470            | 600                    |

### Table 3.4: Summary of M sand properties

| Properties evaluated               | Obtained Value | Standard test method                  |
|------------------------------------|----------------|---------------------------------------|
| Specific Gravity                   | 2.68           | IS:1542-1992                          |
| Water absorption, (%)              | 18             | IS:1542-1992                          |
| Bulk Density (Kg/m³), loose        | 1264           | IS: 2386-1963(PART 3)                 |
| Bulk Density (Kg/m³), compacted    | 1500           | IS: 2386-1963(PART 3)                 |

3.5 Super-Plasticizer
Super plasticizer helps in reducing the water requirement without reduction in strength of the grout, thus improving the flowability and helps in early gain of grout strength. In this investigation we used Sulphonated Naphthalene Formaldehyde and Poly Carboxylic Ether Polymer for the cement grout.

3.6 Fibres
In this study, natural sugar cane fibre is used to enhance crack resisting property to the mixtures, 2.36mm passing size fibres were selected for preparing of samples.

3.7 Selection of aggregate gradations
The three aggregate gradations were identified for preparation of open graded bituminous mixes which allow cement mortar grout flows freely into the voids of mixture with selected quantity of bitumen and compaction. The gradation for the aggregate were adopted according to master gradation provided by the ASTM D7064 (OGFC), New Jersey MOGAC (12.5-mm NMAS) and Transit New Zealand (PA 14 HV) as shown in graph Figure 3.1. Generally, open gradations are preferred for Semi Rigid mixture so that minimum air void content of 20-30% is available in the bituminous mix skeleton. The specimens of different binder content mixes prepared for midpoint aggregate gradations were compacted.

![Figure 3.1: Aggregate gradation graph](image-url)
4. Methodology
The first stage is to develop a cement mortar grout. The second stage is to open graded bituminous mix and finally the production of the Semi rigid mixtures. The following methods were carried on Semi rigid mixtures.

- Selection of Cement Mortar Grout
- Preparation of Open Graded Bituminous Mix Specimens
- Mix design for Semi rigid pavement
- Strength properties
- Durability test.

4.1 Selection of cement mortar grout
Around 22 cementious grouts were evaluated to identify the proportions of grouts for the suitability of semi rigid mixtures. Flowability and strength of the grouts were measured and proportions were changed progressively based on the obtained results. The ratio 1:1 proportion of cement and M sand was fixed and two types of super plasticizer with different dosage were used for water cement ratio of 0.30-0.40. Mixing of the grout was done in a mechanical mixer for three minutes. A summary of cement mortar grout mixtures are shown in Table 4.1.

| Cement Mortar (Cement: M Sand) | Type of Super Plasticizer (SP) | w/c ratio | % of SP dosage |
|--------------------------------|--------------------------------|-----------|----------------|
| 1:1                            | Sulphonated Nepthalene Formaldehyde | 0.30,0.35, 0.40 | 0.25,0.30,0.35, 0.40,0.45,0.50 |
|                                | Poly Carboxylic Ether Polymer         |           |                |

4.1.1 Flowability of cement mortar grout
The flowable properties of cement mortar grouts for two different types of superplasticizer were examined. The flow times of grout are analyzed using effect of superplasticizer dosage and superplasticizer type of flow characteristics are shown in Figure 4.1. From the obtained results, dosage of superplasticizer significantly influence the flowability of cementious grout. According to the trails, the optimal flow time shall be 12 seconds.

Figure 4.1: Flowability of grout containing SP- Sulphonated Nepthalene Formaldehyde and Poly Carboxylic Ether Polymer
4.1.2 Strength properties of cement mortar grout

The strength results for selected grout mixtures containing superplasticizer dosage with flowability 12 seconds are shown in Table 4.1. The compressive and flexural strength of mix for 28 days was carried out. From the results obtained, the grout mix containing 1:1 Cement: M-Sand ratio, 0.35 w/c ratio and 0.45% Poly Carboxylic Ether Polymer dosage produced the highest compressive strength and flexural strength is 27.5 MPa and 3.5 MPa respectively. Table 4.2 shows summary of strength properties of Cement Grouts.

### Table 4.2: Summary of strength properties of Cement Grout

| Cement grout | Super Plasticizer dosage | w/c ratio | Compressive Strength, MPa | Flexural Strength, MPa |
|--------------|--------------------------|-----------|---------------------------|-----------------------|
| Cement: M Sand | Sulphonated Nepthalene Formaldehyde | 0.50 | 0.40 | 21.3 | 2.1 |
| | Poly Carboxylic Ether Polymer | 0.50 | 0.30 | 21.4 | 1.9 |
| 1:1 | | 0.35 | 0.35 | 22.5 | 2.2 |
| | | 0.40 | 0.35 | 24.2 | 2.4 |
| | | 0.45 | 0.35 | 27.5 | 3.5 |
| | | 0.5 | 0.35 | 25.6 | 3.0 |
| | | 0.25 | 0.40 | 25.2 | 2.8 |
| | | 0.30 | 0.40 | 24.6 | 2.5 |
| | | 0.35 | 0.40 | 22.3 | 2.1 |
| | | 0.40 | 0.40 | 21.2 | 1.7 |
| | | 0.45 | 0.40 | 20.6 | 1.5 |
| | | 0.50 | 0.40 | 19.4 | 1.2 |

4.2 Preparation of open graded bituminous mix specimens

Requisite binder content is determined by the method of Marshal Mix design according to codal provision conforming to ASTM-D6927-06. The mixtures were compacted by giving 50 no. of blows on only one face of the specimen using Marshall hammer, for 4 binder contents at an increment of 0.5%. Around 1000gm of aggregates is allowed to heat to a temperature of 160-175°C. Asphalt is melted to a temperature of 150-165°C with the initial experimental percentage of binder (say 4.0 to 5.5 percent by weight of the aggregates). The heated aggregates and binder is carefully batched at 160-165°C temperature. The mixture is then poured inside the heated mould & compacted using a rammer with the 50 number of blow at temperature 130°C to 140°C. The weight of mixed aggregates used for the casting of the sample can be suitably changed to get the desired compacted thickness of 63.5mm. Increase the bitumen content in next trial by +0.5% and repeat the above technique.

4.2.1 Determination of optimal bitumen content (OBC)

The optimal bitumen content was determined for all three gradations by (i) Volumetric analysis of mix, (ii) Abrasion loss, and (iii) Drain down test for the prepared open graded bituminous mix samples. For all gradations, bituminous mixtures were prepared at different binder contents in increment of 0.5%. The minimum criteria for Air void content is of 20% to meet the requirements of open graded bituminous mix samples mixes, The particle loss for the unconditioned samples should not exceed 20% and Drain down loss criteria of 0.3% (maximum) for high void bituminous mix is considered for selecting the optimum binder content.

4.2.1.1 Volumetric analysis of mix

Bulk densities, Gmb (ASTM D2726, 2010) and theoretical maximum specific gravities, Gmm
(ASTM D2041, 2011) of the mix were determined and obtained values were used for volumetric analysis of mix. Voids in Mineral Aggregate (VMA) and Voids in Mix (VIM) and were estimated using equations 4.1 and 4.2 respectively. Figure 4.2 and 4.3 shows VIM and VMA values for binder contents.

\[
VMA = (1 - \frac{G_{mb}}{G_{sb}} \cdot Ps) \times 100 \quad (4.1)
\]

\[
VIM = (1 - \frac{G_{mb}}{G_{mm}}) \times 100 \quad (4.2)
\]

Where,

- \(G_{mb}\) = bulk specific gravity of the mix
- \(G_{sb}\) = bulk specific gravity of aggregates
- \(G_{mm}\) = theoretical specific gravity of the mix
- \(Ps\) = fraction of aggregates present, by total mass of mix

\[\begin{array}{c|c|c|c|c|c}
\text{Binder Content, %} & 4 & 4.5 & 5 & 5.5 \\
\hline
\text{VIM, %} & 37.00 & 38.00 & 39.00 & 40.00 \\
\text{G1} & & & & \\
\text{G2} & & & & \\
\text{G3} & & & & \\
\end{array}\]

\[\begin{array}{c|c|c|c|c|c}
\text{Binder Content, %} & 4 & 4.5 & 5 & 5.5 \\
\hline
\text{VMA, %} & 37.00 & 38.00 & 39.00 & 40.00 \\
\text{G1} & & & & \\
\text{G2} & & & & \\
\text{G3} & & & & \\
\end{array}\]

**Figure 4.2**: VIM values with binder content

**Figure 4.3**: VMA values with binder content

### 4.2.1.2 Cantabro Abrasion loss

Cantabro abrasion loss test was used to determine the abrasion loss value of unaged open graded bituminous mixes using the Los Angeles abrasion machine. The test specimen was placed in a Los Angeles abrasion drum without any abrasive charges, and the machine was operated at a speed of 30–33 revolutions per minute for 300 revolutions. The percentage of weight loss in the specimen when compared to its initial weight was expressed as the unaged abrasion loss (UAL). The temperatures recorded during the test procedure were within the range of 25 ± 5°C as specified in
the ASTM D 7064-08. The result of the test is determined using the Equation 4.3 and Figure 4.4 shows Cantabro abrasion loss for different binder content.

\[ P = \left( \frac{P_1 - P_2}{P_1} \right) \times 100 \] (4.3)

Where,

- \( P \) – Cantabro abrasion loss,
- \( P_1 \) - Initial weight of the sample,
- \( P_2 \) - Final weight of the sample.

![Figure 4.4: Cantabro abrasion loss for different binder content.](image1)

4.2.1.3 Drain down test

The drain-down test is used to determine the correct amount of fiber needed for the mix. The test measures the potential for asphalt binder to drain from the coarse aggregate structure while the mix is held at an elevated temperature. The test is performed in accordance with ASTM D6390. The mass of the drained material is determined to calculate the amount of drain down as a percentage of the mass of the total asphalt mix sample are determined using Equation 4.4 and Figure 4.5 shows drain-down test results for binder contents.

\[ \text{Drain down, } \% = \left( \frac{W_i - W_f}{W_i} \right) \times 100 \] (4.4)

Where,

- \( W_i \) - Initial weight of the sample,
- \( W_f \) - Final weight of the sample.

![Figure 4.5: Drain-down test results for binder contents](image2)
4.2.3 Permeability test

Falling head permeameter was used for conducting the permeability test as per IS Code 2720 part 17. The specimen for determining permeability is prepared by Marshal Method and the specimen is sealed around its periphery on both the sides to prevent the loss of water from sides. Water is allowed to flow through the specimen for a certain head, the time required for the water to pass through the specimen is recorded using stop watch. The resulting permeability cm/s is converted to m/day is determined using the Equation 4.5. Following the typical guidelines for OGFC’s, a minimum value of 100 m/day for permeability should be ensured, so that the cement grout can penetrate the voids in the bitumen mix. Figure 4.6 shows the permeability results for binder contents.

\[
\text{Permeability} = \frac{aL}{L_1} \log\left(\frac{h_1}{h_2}\right) \quad (4.5)
\]

Where,
- \(a\) = area of the top standpipe (cm²),
- \(L\) = height of the sample (cm),
- \(A\) = cross-sectional area of the sample (cm²);
- \(t\) = time taken for the water to fall from \(h_1\) to \(h_2\) (s);
- \(h_1\) = initial water head and
- \(h_2\) = final water head.

Figure 4.6: Permeability results for binder contents

4.3 Preparation of Semi Rigid Mixtures

As discussed in the above sections the optimum range of binder content (OBC 4.5-5.0%) for the selected open graded gradation (G1, G2 and G3) and optimized cement mortar grout (Cement: M Sand: w/c: SP-1:1:0.35:0.45 proportion) will be used to obtain the augmented Semi Rigid mixture samples.

- The open graded bituminous mix were prepared as discussed in the above section.
- The optimized cement mortar grout is identified as explained above section.
- The open graded bituminous mix specimens cooled down to ambient temperature, prepared cementious grout should be poured gradually on the surface of the specimen.
- The care should be taken to prevent spill of grout in mould while pouring.
- The electric vibrator is used for 30 seconds to provide mild vibration to ensure grout penetrated into the mix.
The specimen can be demould after 24 hours and shall be cured for 28 days, direct water curing is not recommended. Wet jute bags can be used for curing.

Photos 4.1 to 4.4 show different stages of preparation of the Semi Rigid mixtures

4.3.1 Properties of grouted mix

The saturation degree and remaining air void (after filling the air void of open graded bituminous mix with grout) in Semi Rigid mixtures are critical parameters concerning the performance and durability of Semi Rigid mixtures under traffic loading and climate conditions. Therefore remaining air void of 3 to 6% for Semi Rigid mixtures should be maintain to avoid bleeding of bituminous mixture. In order to calculate the parameters of grouting saturation degree and remaining air void are calculated using Equation 4.6. The density of grout 1.963 gm/cc is calculated as per BS EN 1015-6 (1999). The Table 4.3 shows summary of volumetric analysis of mixes before and after grouting.

\[
\text{Saturation degree} = \frac{W_2 - W_1}{\rho V + V_a} \tag{4.6}
\]

Where,

W1 and W2 are specimen mass before and after grouting in gram, respectively,
\(\rho\) is the density of grout in gr/cm\(^3\),
V is the specimen volume in cm\(^3\),
Va is the air void of mixtures
### Table 4.3: Summary of volumetric analysis of mixes before and after grouting

| Aggregate Gradation | Binder Content (%) | Avg. weight in air before grouting (gms) | Air voids before grouting (%) | Average weight in air after grouting (gms) | Saturation degree | weight of grout (gms) | Air voids After grouting (%) | Average weight of grout penetrated (gms) |
|---------------------|--------------------|-------------------------------------------|-------------------------------|---------------------------------------------|-------------------|----------------------|------------------------------|------------------------------------------|
| G1                  | 4.5                | 1036                                      | 24.8                          | 1231                                        | 0.79              | 248                  | 5.25                         | 234.97                                   |
|                     | 5                  | 1042                                      | 23.1                          | 1239                                        | 0.85              | 231                  | 3.35                         | 223.25                                   |
|                     | 5.5                | 1048                                      | 21.9                          | 1241                                        | 0.88              | 219                  | 2.56                         | 213.40                                   |
| G2                  | 4.5                | 1039                                      | 24.5                          | 1237                                        | 0.81              | 245                  | 4.65                         | 233.60                                   |
|                     | 5                  | 1042                                      | 23.2                          | 1241                                        | 0.86              | 232                  | 3.25                         | 224.45                                   |
|                     | 5.5                | 1050                                      | 22.3                          | 1246                                        | 0.88              | 223                  | 2.65                         | 217.08                                   |
| G3                  | 4.5                | 1037                                      | 24.8                          | 1234                                        | 0.80              | 248                  | 5.05                         | 235.46                                   |
|                     | 5                  | 1041                                      | 23                            | 1237                                        | 0.85              | 230                  | 3.35                         | 222.28                                   |
|                     | 5.5                | 1051                                      | 21.7                          | 1247                                        | 0.91              | 217                  | 2.05                         | 212.54                                   |

### 5 Results and discussion

#### 5.1 Compressive strength

Compressive strength of compacted asphalt mixtures is measured as per ASTM D1074 by Compressive Testing Machine (CTM). The same method was adopted to test Semi Rigid mixture samples, the sample preparation is explained in above section and dimensions of the cylindrical samples are 101.6mm diameter and 63.5mm thickness. Figure 5.1 shows compressive strength values of binder contents and Equation 5.1 shows compressive strength values in N/mm².

Compressive strength= \( \frac{P}{A} \) N/mm² \hspace{1cm} (5.1)

Where,

- \( P \) = maximum applied load in N
- \( A \) = area of the sample in mm²

![Figure 5.1: Compressive strength values of binder contents](image-url)
5.2 Flexural Strength

ASTM C 78 test method provides a method for measuring flexural strength of the concrete. The same method was adopted to test Semi Rigid mixture samples, the dimensions of mould size are 500mm*100mm*100mm. The open graded bituminous mix for the optimum binder contents (4.5-5.5%) is poured on the beam mould, CTM is used to compact the mix to obtain target air voids 20-30% and optimized cement mortar grout (1:1:0.35:0.45) is poured on the mixture when it cools down to ambient temperature. After 24 hours the beam sample were demould and kept for 28 days water curing. Two point loading test carried on the sample, point of failure at maximum load recorded for calculating flexural strength test. Figure 5.2 shows the flexural strength values of binder contents and Equation 5.2 shows flexural strength values in N/mm².

Flexural strength = \( \frac{pl}{bd^2} \)  

Where,

\( P = \) Failure load in N  
\( L = \) Effective span of the beam in mm 
\( b = \) Breadth of the beam in mm  
\( d = \) Depth of the beam in mm

![Figure 5.2: Flexural strength values of binder contents](image)

5.3 Marshall Stability

Marshall Method is used almost everywhere in the world for its easy procedure and economy compared to other methods. Strength behavior of samples at optimum binder contents were studied using Marshall Stability. ASTM D6927 test method used for testing procedure of the samples. The cylindrical samples of 101.6mm diameter and 63.5mm thickness were cast to test the stability with 50blows of compaction on single side to obtain target air voids 20-30%. The point of failure is defined when the maximum load reading obtained and maximum load value is expressed in kN is recorded as the Marshall Stability value of the samples. Figure 5.3 shows the stability values of binder contents.
5.4 Indirect Tensile Strength

Indirect tensile strength test performed to study the tensile behavior of Semi rigid mixtures. The Indirect Tensile Strength (ITS) was determined as per ASTM D6931-17 on cylindrical samples by loading them along a diametrical axis at a deformation rate of 51 mm per minute. The same method was adopted to test Semi Rigid mixture samples. The maximum load P, taken by the specimen was used to calculate the indirect tensile strength. The ITS value can be determined by Equation 5.3 and Figure 5.4 shows the ITS value of conditioned and unconditioned for binder contents.

\[
\text{ITS} = \frac{2000P}{\pi \cdot t \cdot d} \tag{5.3}
\]

Where,

\(\text{ITS}\) = Indirect Tensile Strength in N/mm²

\(P\) = maximum applied load in N

\(t\) = mean thickness of sample in mm

\(d\) = diameter of sample in mm
5.5 Durability
Cantabro abrasion test conducted at temperature of 25°C in Las Angeles drum, rotated for 300 revolutions. This test is generally conducted on both dry and wet conditioned specimen as specified in the ASTM D 7064 -08. To study worst condition, aged samples were used in the present study. The samples were conditioned for 168 hours at 40°C and samples are then cooled to 25°C and stored for 4 hours prior to abrasion. The result of the test is determined using the Equation 5.4. Figure 5.5 shows Cantabro abrasion loss for binder contents.

\[ P = \frac{(P_1 - P_2)}{P_1} \times 100 \]  
Where,
\( P \) – Cantabro abrasion loss,
\( P_1 \) – Initial weight of the sample,
\( P_2 \) – Final weight of the sample.

6 Conclusions
This current study investigated the engineering and strength properties of Semi Rigid mixtures. In the first stage of this study, the effect of flowability and strength properties of cement mortar grout was evaluated. In the next stage, the open graded bituminous mix, which is the skeleton of the Semi Rigid mixtures, was designed to find optimum binder content by air voids drain down and abrasion loss was evaluated. Finally, Semi Rigid mixtures specimens were prepared by grouting cement mortar into an open graded bituminous mix. Mechanical properties including compressive strength, flexural strength, Marshall Stability, tensile strength and durability were evaluated for optimum binder content. From the test results it was clearly recommended that the air voids 20-30% and filling rate of Semi Rigid mixtures specimens were greatly influenced by the flowability of cement grout within 12 seconds. Through evaluating the strength characteristics compressive strength, flexural strength, Marshall Stability, tensile strength and durability it was found that the 4.5% binder content have higher values compare to 5.0% binder content due to increase in void content and cement grout.

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