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# PERFORMANCE STUDIES ON BITUMINOUS MIXES USING CRUMB RUBBER MODIFIED BITUMEN

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## ABSTRACT

**The bitumen modification using rubber for improving performance of binder is known from many years. In recent years the crumb rubber modified binders have become popular as they consume the used tires and exhibit better performance. In addition to the advantages that are attributed to the crumb rubber modified binders there are some disadvantages associated with them like storage stability problem, which necessitates remixing the blend every time before using it and hot recycling of the deteriorated pavement made with CRMB is not permitted in many countries, as it causes so much air pollution.**

**In India discarded bi-cycle tires are available in plenty and shredding them is easy. So, here we made an attempt to modify the bitumen using shreds of bi-cycle tires. In this modification process, 80/100 bitumen is mixed with the tire shreds of 1cm X 1cm size at optimum blending conditions and then the tire shreds are filtered out using a wire mesh. In this study clean (washed and dried) and unclean tire shreds were used. Optimum blending conditions at a blending temperature of 165 °C were considered to be blending time of ¼ hr. mixing + 1 hr. reaction + ½ hr. mixing and tire shred concentration of 15% by weight of bitumen. A spindle was designed to the available stirrer for homogeneous blending. The properties of the clean tire shred modified binder were superior to properties of unclean tire shred modified binder and neat 80/100 binder; and storage stability problem is almost absent.**

**Marshall Tests and static indirect tension test were conducted on DBM mixes (MORTH gradation 2) with clean, unclean tire shred modified binders and 80/100 bitumen at 5 different binder contents. The results of the indirect tension tests conducted at 5 °C, 25 °C, 40 °C temperatures showed that the improvement in the performance of the mix is significant at lower temperatures and higher binder contents. Modulus of resilience values were evaluated for the mixes with clean modified and 80/100 binders at the binder contents for which Marshall criteria given in MORTH are satisfied. MR value of the mix at optimum binder content was significantly improved with clean tire shred modified binder over 80/100 bitumen that the structural layer thickness requirement of 161 mm with 80/100 bitumen has come to 100 mm with clean modified binder.**

**KEY WORDS :Modified binder, Performance, Crumb rubber, Clean and Unclean tire shreds, Storage stability, Marshall Properties.**



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## I. INTRODUCTION

### 1. A USE OF CRUMB RUBBER IN PAVEMENT CONSTRUCTION

In India, truck population increased by about ninety times during the last five decades. Millions of tires are discarded every year in India. Of these, about 20% are retreaded and about 15% are diverted to various alternative uses. The remaining are added to stockpiles, landfills or illegal dumps. Retreading of old truck and bus tires is done extensively in all parts of India in small retreading shops. Crumb rubber is generated during the scraping of the old tires.

In India, Ministry of Road Transport and Highways has issued circulars for use of modified bitumen in ten percent of the bituminous construction. As vast quantity of crumb rubber, which has been known to improve properties of mixes, are available as waste material from retreading shop in India, the same can be used beneficially to modify normal bitumen which is available cheaply and abundantly. It is expected that the use of the crumb rubber modified material in paving application will increase.

### 1. B METHODOLOGY / WORK PLAN

- Literature review
- Selection of appropriate tire shred concentration to start with and blending parameters from the literature.
- Finding the optimum blending time for the tire shred concentration selected.
- Finding the optimum tire shred concentration with the blending parameters finalized in the previous step.
- Casting the Marshall specimens with 5 different binder contents for Marshal testing, static indirect tension test.
- Finding the binder contents at which the Marshall criteria are satisfied.
- Conducting Static indentation test on Marshall specimen with maximum binder content at which the Marshall criteria are satisfied.
- Conducting the Repeated load indirect tension test on the sample at binder contents at which the Marshall criteria are satisfied.
- Estimating the amount of savings in the materials required for a pavement when modified binder is used instead of neat bitumen

## II. BLENDING CONDITIONS

Blending conditions adopted by different researchers, available in literature are summarized as follows:

**Table 2.1** Summary of Literature on Blending Conditions

| AUTHORS (references) | MIXING TEMPERATURE °C | STIRRING SPEED rpm | RUBBER/ CRUMB % | MIXING DURATION Minutes |
|---|---|---|---|---|
| Charles H. Mc. Donald.(ref. 3) | 190 | - | 25 | 20 |
| Billiter et al. (2) | 232-260 | 8000-4000 | 10 | 90-120 |
| Daly and Negulescu(4) | 170 | high speed | 10 | 60 |
| Roberts and Lytton(1) | 190 | 500 | 15 | 60 |
| Palit S.K. (3) | 180 | 2000 | 10 | 40 |
| Bahia and Davis(10) | 160±5 | high speed | 20 | 60 |
| Harvey and Monismith(9) | 177 | high speed | - | 60 |
| Hussain et al. (5) | 175 | medium speed | - | 70-80 |
| Lalwani et al. (8) | 200 | 250 | - | ≥60 |
| Brown et al. (7) | 171 | - | - | 35 |
| Abdelrahman and Carpenter (6) | 160-240 | 80 | 10 | 60-100 |
| Khedaywi et al. (12) | 160 | 500 | - | 30 |

## III.DEVELOPMENT OF TIRE SHRED MODIFIED BINDER

### 2. A PROPERTIES OF MODIFIED AND UNMODIFIED BINDERS

The results of specific gravity, penetration softening point and ductility tests conducted on the binders are presented in table 3.A.

Here after bitumen modified with clean and unclean tire shreds will be referred to as **clean** and **unclean** respectively. Neat binder will be referred to as **80/100** or binder modified with **0%** tire shreds.

**Table 3.A** Properties of Unmodified and Tire Shred Modified Binders

| Binder Property | Tire shred type | % of tire shreds | | | |
|---|---|---|---|---|---|
| | | (80/100) | | | |
| | | 0 | 10 | 15 | 20 |
| Penetration (1/10 mm) | Clean | 90 | 60 | 55.2 | 54.5 |
| | Unclean | 90 | 61 | 55.1 | 54.7 |
| Softening Point ($^0$ C) | Clean | 42 | 46 | 49 | 50 |
| | Unclean | 42 | 46 | 49.5 | 50.5 |
| Ductility Value (cm) | Clean | 100 | 68 | 62 | 59 |
| | Unclean | 100 | 60 | 56 | 47 |
| Elastic Recovery (%) | Clean | 30.7 | 46.3 | 56.7 | 59 |
| | Unclean | 30.7 | 48.2 | 54 | 54 |
| Flash Point ($^0$ C) | Clean | 336 | 338 | 338 | 337 |
| Specific gravity | Clean | 1.02 | 1.028 | 1.031 | 1.031 |

### 3. B Viscosity-Temperature Relationship

Brook-Field Viscometer was used to determine the viscosity characteristics of different binders. Another aim of carrying out these tests was to determine the mixing and compaction temperatures for preparing Marshall Specimens. The absolute viscosity determined from Brook-Field viscometer tests was converted to kinematic viscosity for finding mixing and compaction temperatures, Results of the viscosity tests are presented in figure 3.6.

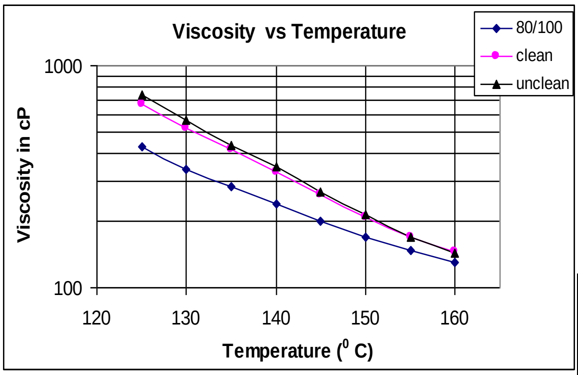


**Fig. 3.6 Variation of Binder Viscosity with Temperature**

IV.MIX DESIGN

### 4. A Materials Used

Crushed stone chips collected from Kalyam quarry in West Bengal (India) were used as coarse aggregates and aggregate from Rampurahat was used as fine aggregates and filler (stone dust) in this investigation. Properties of aggregates and gradation adopted are presented in tables 4.1 and 4.2 and figure 4.1

**Table 4.A Physical Properties of Aggregates and Filler used**

| Materials | Property Tested | Value |
|---|---|---|
| Coarse aggregate | Specific gravity<br>Water absorption<br>Los Angeles Abrasion value<br>Aggregate Impact value<br>F.I. + E.I. | 3.055<br>0.77%<br>23%<br>11%<br>29% |
| Fine aggregate | Specific gravity | 2.89 |
| Filler ( stone dust ) | Specific gravity | 2.828 |

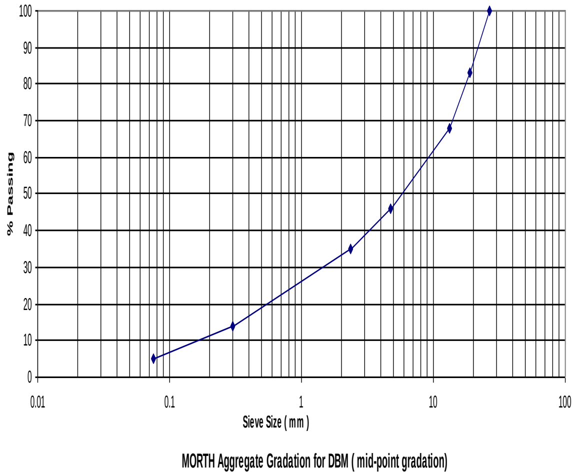


**Figure 4.A Aggregate Gradation**

**Table 4.B Aggregate Gradation adopted in Mix Design**

| Sieve Size (mm ) | 25 | 19 | 13.2 | 9.5 | 4.75 | 2.36 | 0.3 | 0.075 |
|---|---|---|---|---|---|---|---|---|
| % passing | 100 | 83 | 68 | 56 | 46 | 35 | 14 | 5 |

Mixing temperatures of 155°C and 150°C were adopted for modified binders and 80/100 neat binder respectively. Five different binder contents were chosen for testing, they are 4.5, 5.0, 5.5, 6.0 & 6.5% by weight of aggregate.

### 4. B MARSHALL SPECIMEN PREPERATION AND TESTING

Marshall tests are conducted after keeping the specimen in a water bath maintained at 60$^0$C for a period of 30 minutes. Some of the Marshall specimens are shown in Plate 4.A.

**Plate 4.A Marshall Specimens**

Marshall properties of mixes with Clean, Unclean modified binders and 80/100 binder are presented in **Tables 4.4, 4.5 and 4.6** respectively and average values are presented in **Table 4.7.**

**Table 4.4** Marshall Properties of Mixes with **Clean** Tire Shred Modified Binder

| Binder/aggregate in mix % | Sample No. | Density (gm/cc) | Corrected Stability(KN) | Flow mm | VMA % | AV % | VFB % |
|---|---|---|---|---|---|---|---|
| 4.5 | 2 | 2.62 | 12.6 | 2.75 | 14.4 | 6.9 | 52.1 |
| 4.5 | 3 | 2.61 | 11.8 | 4 | 14.9 | 7.4 | 50.1 |
| 4.5 | 4 | 2.59 | 11.0 | 3.75 | 15.3 | 7.9 | 48.6 |
| 5.0 | 1 | 2.62 | 11.6 | 3.5 | 14.4 | 6.1 | 57.4 |
| 5.0 | 4 | 2.63 | 12.2 | 3.25 | 14.2 | 5.9 | 58.2 |
| 5.0 | 5 | 2.61 | 11.8 | 3.5 | 14.8 | 6.6 | 55.5 |
| 5.5 | 2 | 2.62 | 10.6 | 2 | 14.4 | 5.5 | 62.1 |
| 5.5 | 3 | 2.63 | 11.7 | 4.5 | 14.0 | 5.0 | 64.2 |
| 5.5 | 5 | 2.62 | 13.0 | 5.5 | 14.5 | 5.6 | 61.6 |
| 6.0 | 1 | 2.61 | 9.7 | 6.5 | 14.8 | 5.1 | 65.3 |
| 6.0 | 3 | 2.60 | 8.4 | 5.5 | 15.2 | 5.7 | 62.9 |
| 6.0 | 6 | 2.61 | 9.3 | 4 | 14.8 | 5.1 | 65.2 |
| 6.5 | 1 | 2.61 | 7.2 | 6 | 14.7 | 4.4 | 70.3 |
| 6.5 | 2 | 2.62 | 9.6 | 4.5 | 14.4 | 4.0 | 71.9 |
| 6.5 | 6 | 2.62 | 9.0 | 6.5 | 14.6 | 4.2 | 70.8 |

**Table 4.5** Marshall Properties of Mixes with **Unclean** Tire Shred Modified Binder

| Binder/aggregate in mix % | Sample No. | Density (gm/cc) | Corrected Stability(KN) | Flow mm | VMA % | AV % | VFB % |
|---|---|---|---|---|---|---|---|
| 4.5 | 2 | 2.61 | 12.4 | 4 | 14.8 | 7.4 | 50.4 |
| 4.5 | 3 | 2.61 | 11.3 | 3.75 | 14.7 | 7.2 | 51.2 |
| 4.5 | 5 | 2.60 | 10.1 | 5.5 | 15.2 | 7.8 | 48.9 |
| 5.0 | 1 | 2.61 | 10.5 | 5 | 14.8 | 6.6 | 55.6 |
| 5.0 | 2 | 2.61 | 10.6 | 4 | 14.7 | 6.5 | 56.0 |
| 5.0 | 3 | 2.61 | 11.0 | 4 | 14.9 | 6.7 | 55.2 |
| 5.5 | 1 | 2.63 | 11.3 | 6.5 | 14.1 | 5.2 | 63.5 |
| 5.5 | 4 | 2.62 | 8.7 | 3.5 | 14.5 | 5.5 | 61.7 |
| 5.5 | 6 | 2.61 | 10.3 | 5.5 | 14.9 | 6.0 | 59.8 |
| 6.0 | 1 | 2.62 | 9.2 | 5.5 | 14.6 | 5.0 | 66.0 |
| 6.0 | 3 | 2.63 | 8.4 | 5 | 14.1 | 4.4 | 68.7 |
| 6.0 | 4 | 2.62 | 10.3 | 4.25 | 14.5 | 4.8 | 66.8 |
| 6.5 | 1 | 2.62 | 8.6 | 6.5 | 14.5 | 4.2 | 71.3 |
| 6.5 | 3 | 2.62 | 10.9 | 4.5 | 14.5 | 4.2 | 71.2 |
| 6.5 | 6 | 2.61 | 8.0 | 6 | 14.7 | 4.4 | 70.0 |

**Table 4.6** Marshall Properties of Mixes with **80/100** Binder

| Binder/aggregate in mix % | Sample No. | Density (gm/cc) | Corrected Stability(KN) | Flow mm | VMA % | AV % | VFB % |
|---|---|---|---|---|---|---|---|
| 4.5 | 2 | 2.60 | 11.3 | 5.5 | 15.3 | 7.7 | 49.6 |
| 4.5 | 4 | 2.62 | 13.0 | 2.25 | 14.5 | 6.9 | 52.6 |
| 4.5 | 5 | 2.60 | 12.3 | 2 | 15.1 | 7.5 | 50.3 |
| 5.0 | 1 | 2.61 | 11.6 | 3.25 | 14.8 | 6.5 | 56.3 |
| 5.0 | 2 | 2.62 | 12.8 | 2.5 | 14.4 | 6.0 | 58.3 |
| 5.0 | 3 | 2.61 | 13.4 | 4.5 | 14.8 | 6.5 | 56.4 |
| 5.5 | 4 | 2.60 | 8.8 | 3 | 15.2 | 6.2 | 59.4 |
| 5.5 | 5 | 2.59 | 9.4 | 2 | 15.5 | 6.5 | 58.0 |
| 5.5 | 6 | 2.63 | 10.5 | 3.5 | 14.2 | 5.0 | 64.5 |
| 6.0 | 1 | 2.61 | 9.9 | 4 | 14.9 | 5.1 | 65.6 |
| 6.0 | 3 | 2.62 | 9.4 | 4.5 | 14.6 | 4.8 | 67.3 |
| 6.0 | 5 | 2.62 | 10.3 | 4.4 | 14.6 | 4.8 | 67.0 |
| 6.5 | 1 | 2.60 | 9.1 | 6.75 | 15.1 | 4.6 | 69.3 |
| 6.5 | 2 | 2.61 | 9.0 | 5.6 | 14.9 | 4.3 | 70.9 |
| 6.5 | 3 | 2.60 | 8.1 | 6 | 15.2 | 4.7 | 69.2 |

**Table 4.7** Marshall Parameters of different Mixes tested (Average values of 3 samples)

| Binder | Binder/aggregate in mix % | Stability (KN) | Flow (mm) | Density (gm/cc) | VMA % | AV % | VFB % |
|---|---|---|---|---|---|---|---|
| **Clean** | | | | | | | |
| | 4.5 | 11.8 | 3.50 | 2.61 | 14.89 | 7.41 | 50.27 |
| | 5.0 | 11.8 | 3.42 | 2.62 | 14.46 | 6.22 | 57.04 |
| | 5.5 | 11.8 | 4.00 | 2.63 | 14.32 | 5.35 | 62.66 |
| | 6.0 | 9.1 | 5.33 | 2.61 | 14.92 | 5.31 | 64.45 |
| | 6.5 | 8.6 | 5.67 | 2.62 | 14.53 | 4.21 | 71.01 |
| **Unclean** | | | | | | | |
| | 4.5 | 11.3 | 4.42 | 2.61 | 14.98 | 7.37 | 50.83 |
| | 5.0 | 10.7 | 4.33 | 2.61 | 14.68 | 6.32 | 56.99 |
| | 5.5 | 10.1 | 5.17 | 2.62 | 14.94 | 5.89 | 60.65 |
| | 6.0 | 9.3 | 4.92 | 2.62 | 14.69 | 4.91 | 66.62 |
| | 6.5 | 9.2 | 5.67 | 2.62 | 15.05 | 4.55 | 69.79 |
| **80/100** | | | | | | | |
| | 4.5 | 12.2 | 3.25 | 2.60 | 14.91 | 7.43 | 50.17 |
| | 5.0 | 12.6 | 3.42 | 2.61 | 14.78 | 6.56 | 55.59 |
| | 5.5 | 9.6 | 2.83 | 2.61 | 14.52 | 5.57 | 61.67 |
| | 6.0 | 9.9 | 4.30 | 2.61 | 14.41 | 4.73 | 67.16 |
| | 6.5 | 8.73 | 6.12 | 2.60 | 14.55 | 4.24 | 70.85 |

Variation of different Marshall Properties with binder content for different binders is presented in the **figures 4.2, 4.3, 4.4, 4.5, 4.6, 4.7.**

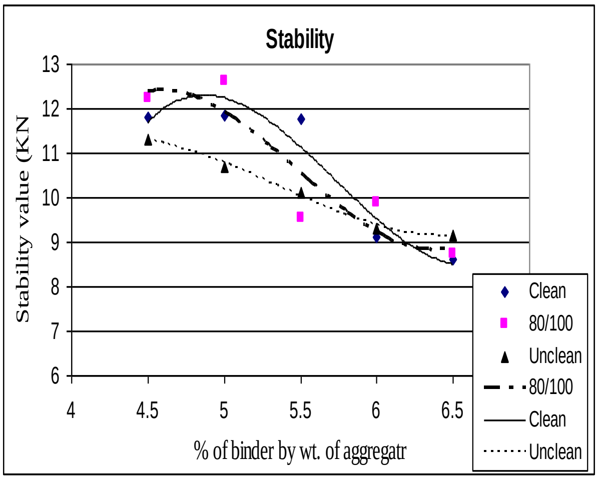


**Fig. 4.2 Variation of Marshall Stability with Binder Content**

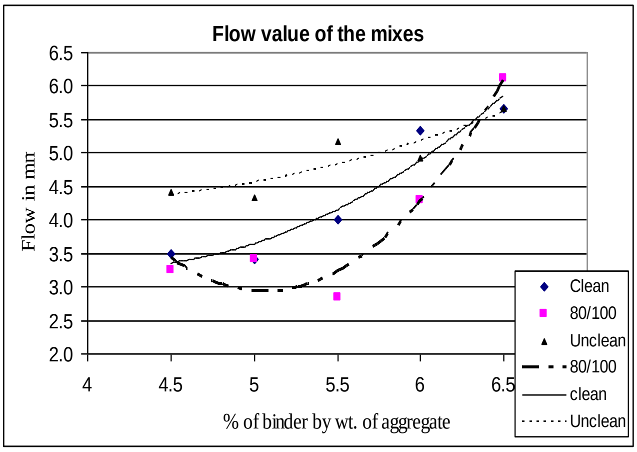


**Fig. 4.3 Variation of Flow Values with Binder Content**

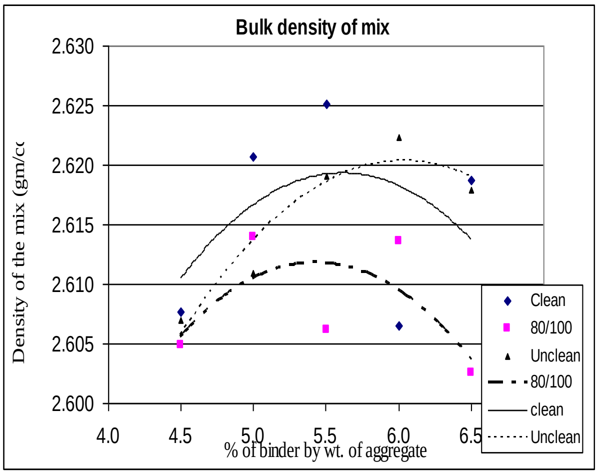


**Figure 4.4 Variation of Bulk Density with Binder Content**

**5.1 CONCLUSIONS**

The results of the tests conducted on tire shred modified and unmodified binders and the mixes prepared using these binders, lead us to the following broad conclusions:

*Binder properties*

- Optimum blending time was found to be ¼ hr. mixing + 1 hr. reaction + ½ hr. mixing , for mixing temperature of 165 °C, tire shred size of 1cm X 1cm (and tire shred concentration of 15%).
- 15% tire shred concentration was found to be optimum, as the improvement in the binder properties beyond this (15%) is not significant for mixing temperature of 165 °C and blending time of ¼ hr. mixing + 1 hr. reaction + ½ hr. mixing.
- The clean modified binder performance is superior to that of unclean modified binder. Even though the penetration and softening point values of both clean and unclean modified binders are similar, there is significant variation in the ductility and elastic recovery values, the variation may be due to the presence of dirt with the unclean tire shreds.
- The storage stability problem is almost absent in clean tire shred modified binder, as expected.
- There is little improvement in the flash point and specific gravity values of the modified binder, compared to the neat bitumen
- The loss on heating for 80/100 bitumen is little, it is even less for Clean modified binder. So, Clean modified binder exhibits higher resistance to oxidative hardening / ageing.

*Properties of the Mixes*

- Marshall stability values of mixes with clean modified binder are slightly greater than those of mixes with 80/100 bitumen, even though the flow values decreased for mixes with clean modified binder compared to 80/100 binder no fixed trend was observed.
- Pavement thickness requirement with mix having clean modified binder is significantly less than the requirement with conventional 80/100 bitumen.
- The mixes with unclean tire shred modified binder have not shown any considerable improvement in the properties of the mix.

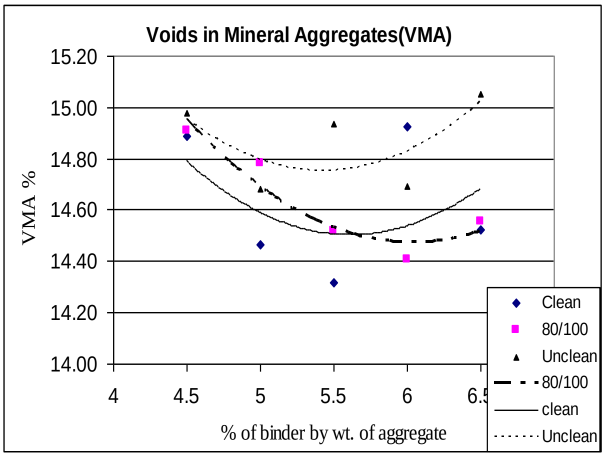


**Fig. 4.5 Variation of VMA with Binder Content**

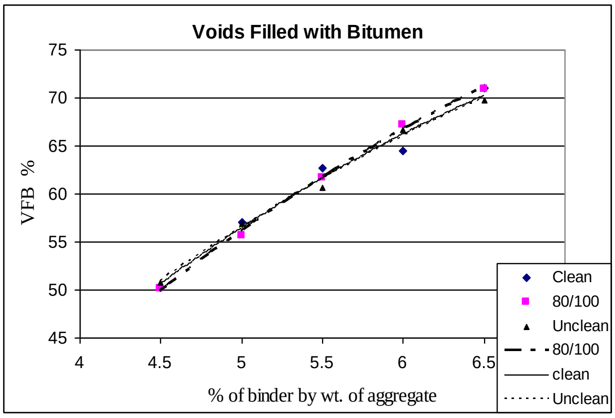


**Fig. 4.7 Variation of VFB with Binder Content**

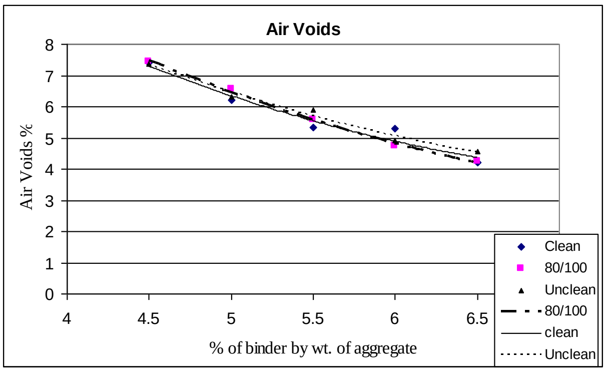


**Fig. 4.6 Variation of Air Voids with Binder Content**

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