Using Crumb Rubber to Improve the Bituminous Mixes: Experimental Investigation of Rutting Behavior of Flexible Asphalt Mix for Road Construction

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Abstract. Tires that are simply thrown away are a serious environmental problem and safe disposal is a difficult problem. Using the crumb rubber (CR) obtained from shredding of those scrap tires in roads is an alternative solution to their safe disposal. On the other side, excessive rutting in the bituminous layer is a structural defect associated with functional implications. Wheel loads and high pavement temperatures are environmental factors which the main cause of premature rutting. Modified binders and rut resistant mixes especially gradations can reduce premature rutting. The object of the paper to solve two main problems: firstly, the solution to the problem of the tires waste to safe disposal and; secondly, to study the rutting behaviour in bituminous mixes modified by tires waste in CR form. In this paper, two types of bituminous mixes, stone matrix asphalt and bituminous concrete those are used to carry wheel tracking test. The results are shown by using Marshall Test that 6% of CR content by weight if normal binder 60/70 content and optimum binder content for the binder in bituminous mixes is 5.1% & 5.5% by weight of mix is have improved the bituminous mixes. In addition, results indicated that the mixes prepared with a modified binder by CR are good in forming rut resisting mixes. The benefit of this study is the tires waste disposal in an environment-friendly way and better road to withstand rutting.

Keywords: Bituminous Mixes; Crumb Rubber; Marshall Test, Rutting resistant.

1. Introduction
Nowadays the disposal of different wastes produced from different industries is a great problem. Tires represent a serious environmental concern on several fronts. Part of the risk lies with their chemical makeup. Toxins released from tire decomposition, incineration or...
accidental fires can pollute the water, air and soil. Besides, tires are also a problem in landfills: their hollow, rounded shape takes up the valuable shape in landfills. Application of the scrap tires in roads is an alternative solution to their safe disposal and such studies are already in progress [1 – 4]. Besides that, bituminous mixes have been exposed to greater stresses because of the increasing traffic volumes, higher axle loads than the allowable and high tire pressures and added to increasing temperatures in summer. These increases stress pose different forms of failures like fatigue, permanent deformation and surface wear in the early years of the pavement service life. One of the most important forms of distress is the permanent deformation in wheel paths of bituminous layers which may influence the steering of vehicles at high speeds and hydroplaning, [5].

Rutting which is also known as permanent deformation can be defined as the accumulation of small amounts of unrecoverable or permanent strains due to repeated application of wheel loads. Research studies indicated that shear deformation rather than densification was the primary rutting mechanism within the bituminous mix [6-8].

To minimize the deterioration and to increase the long-term durability of the flexible pavement, the bituminous layers should be improved with regard to performance-related properties such as resistance to permanent deformation, load associated fatigue and ageing. One way of increasing the quality of a flexible material layer is the use of high-quality bitumen by adding modifiers. Bitumen modification offers one solution to overcome the deficiencies of bitumen and improve the performance of bituminous mixtures [1-9].

The purpose of the present study is to investigate the properties of four types of binders, Normal binder 60/70; crumb rubber modified binder, to evaluate the Marshall Properties of BC and SMA Mixes prepared with (60/70) and CRMB, to identify the optimum CRMB content based on Marshall Tests and to evaluate rutting susceptibility of different bituminous mixes prepared with different binders to study permanent deformation behaviour.

2. Preparation of Crumb Rubber Modified Asphalt (Wet Process)

The wet process defines any method that adds the CR obtained from the shredding of the scrap tires to the bitumen before incorporating the binder into the asphalt-paving mix. The wet process which includes blending the CR and asphalt cement to produce the CRMB. The scrap tires were shredded into pieces. When preparing the modified bitumen’s, about 1000 g of the bitumen was heated to a fluid condition in a 2-litre capacity container. As the bitumen attained a temperature of 170°C, the different CR contents by mass (3%, 6% & 9%) were added to the heated bitumen. For blending the bitumen (60/70) with the CR, a mechanical stirrer was used. Fig. (1) Show the micrographs of crumb rubber powder (CRP).
3. Basic Mix Properties

The present study is to study the permanent deformation behaviour in bituminous mixes therefore we are used Bituminous concrete (BC) and the stone matrix asphalt (SMA).

3.1 Binder Test Results

Different tests were carried 60/70 penetration grade binder, CRMB-3%, CRMB-6%, CRMB-9% binder. Table (1) presents physical properties for 60/70 grade binder.

| Sl. No | Property                                           | Test Result | Standard Value | IS Code  |
|-------|----------------------------------------------------|-------------|----------------|----------|
| 1     | Flash point, by COC °C, min                        | 230°C       | 220            | IS 1290  |
| 2     | Penetration at 25°C, 0.1 mm, 100g, 5 sec          | 61          | 50-70          | IS 1203  |
| 3     | Softening Point, (R&B), °C min                     | 48°C        | 47             | IS 1205  |
| 4     | Specific gravity at 27°C                           | 1.02        | 0.9-1.02       | IS 1202  |
| 5     | Ductility at 27°C, cm                              | 85          | 50-100         | IS 1208  |
|       | Tests on Residue from Thin Film Oven Tests         |             |                |          |
| 6     | Loss in Weight, %, max                             | 0.55%       | 0.4%           | IS:1203  |
| 7     | Reduction in Penetration of Residue at 25°C, %, max| 57%         | -              | IS 1203  |

Table (2) presents physical properties for crumb rubber modified binder. From the test result, the crumb rubber modified binder can be graded as CRMB-3%, CRMB-6% and CRMB-9%.
Table 2. Properties of Rubber Modified Binders (IRC SP: 53, 2002)

| Sl. No | Designation                                                                 | Test Result CRMB-3% | Test Result CRMB-6% | Test Result CRMB-9% | Sta. V. | IS Code       |
|-------|------------------------------------------------------------------------------|---------------------|---------------------|---------------------|---------|---------------|
| 1     | Penetration at 25°C, 0.1 mm, 100g, 5 sec                                     | 55                  | 60                  | 68                  | <50     | IS 1203-1978 |
| 2     | Softening Point, °C (R&B) min                                                | 55                  | 61°C                | 59                  | 60      | IS 1205-1978 |
| 3     | Flash point, COC °C, min                                                     | 220                 | 240°C               | 250                 | 220     | IS 1206-1978 |
| 4     | Elastic Recovery of Half Thread at 15°C, %, max                              | 45%                 | 50%                 | 50%                 | 50      | Appendix-1    |
| 5     | Specific gravity                                                            | 1.02                | 1.04                | 1.05                | -       | IS 1202–1978 |

Thin Film Oven Test (TFOT) on Residue (D1754/D1754M-09)

| Sl. No | Property                                                                 | Test Value | Specified Limits | Code               |
|-------|--------------------------------------------------------------------------|------------|------------------|--------------------|
| 6     | Increase in Softening Point, (R&B), °C, max                               | 4%         | 5%               | IS 1205-1978       |
| 7     | Penetration at 25°C, 0.1mm, 100g, min % of                               | 50%        | 60%              | IS 1203-1978       |

3.2 Aggregate physical properties

Aggregate particles were tested for the following properties as per MORTH specifications. Summary of the values observed for the aggregate particles are presented in Table (3).

Table 3. Properties of Aggregates

| Sl. No | Property                                                | Test Value | Specified Limits | Code               |
|-------|---------------------------------------------------------|------------|------------------|--------------------|
| 1     | Specific gravity for coarse aggregation                 | 2.87       | 2.5 - 3.0        | IS 2386 part 4     |
| 2     | Specific gravity for Fine aggregation                   | 2.63       | 2.5 - 3.0        | ASTM C127          |
| 3     | Particle Shape (Flakiness & Elongation index), %        | 16         | Max 30 (combined) | IS 2386 part 1     |
| 4     | Strength                                                | 21         | Max 24           | IS 2386 part 4     |
| 5     | Aggregate Crushing Value, %                             | 25.4       | Max 45           | IS 2386 part 4     |
| 6     | Los Angeles abrasion Value, %                           | 30         | Max 30           | IS 2386 part 4     |
| 7     | Stripping (Coating and Stripping of Bitumen Aggregate Mixtures) | 99         | Min retained Coating 95 | IS 6241    |
| 8     | Stripping for CRMB, 3%                                   | 100        | Min retained Coating 95 | IS 6241    |
| 9     | Stripping for CRMB, 6%                                   | 99         | Min retained Coating 95 | IS 6241    |
| 10    | Stripping for CRMB, 9%                                   | 95         | Min retained Coating 95 | IS 6241    |
4. Marshall Test Results

BC and SMA mixes are to be prepared with 60/70, CRMB (3%, 6% & 9%) as per ASTM D1559. Optimum CR content is to be determined based on Marshall Test results for the mixes prepared with varied CR contents and optimum bitumen content.

Figures (2 to 3) present the Marshall stability, bulk density, and flow air voids for the BC and SMA mixes prepared with normal binders respectively. Similarly, figures (4 to 5) present the Marshall Stability, bulk density, air voids and flow for the BC and SMA mixes prepared optimum binder 60/70 and CRMB binders respectively.

![Figure 2](image1.png)  
**Figure 2.** Variation of (a) Stability & (b) Bulk Densities for BC and SMA mixes with 60/70

![Figure 3](image2.png)  
**Figure 3.** Variation of (a) Air voids & (b) Flow for BC and SMA mixes prepared with 60/70

It can be observed that the stability and bulk density values follow similar trends and maximum values can be obtained at (5.1% of BC & 5.5% of SMA) binder content. Also, (5.1% & 5.5%) binder content was observed at 4% air voids. Finally, an optimum binder content of (5.1% of BC & 5.5% of SMA) was fixed and the same binder content was used to identify the optimum crumb rubber content for bituminous mixes.
Figure 4. (a) Marshall Stability, (b) Bulk Density with NB and CRMB for BC & SMA Mixes

Figure 5. (a) Flow & (b) Air Voids with NB and CRMB for BC and SMA Mixes

It can be seen from figures (4) to (5) that up to 6% CR content, the density and stability are increasing and thereafter a further increase in CR content, the values are decreasing. Hence, the optimum CR content of 6% was selected to address the rutting characteristics.

5. Laboratory Investigation on Rutting (Wheel Tracking Test)

Wheel tracking test was developed by the British National Rail Road Institute (BNRRRI) can be used to study the rut characteristics of different HMA pavements and the rut characteristics of different subgrade materials. With a view to carrying out small scale laboratory-based simulated wheel track tests to evaluate permanent deformation characteristics, bituminous concrete (BC) and (SMA) slabs were prepared with 60/70 grade and CRMB-6%. The rut depth of track is measured with a lapsed number of load repetitions on a test specimen surface. Permanent deformation values after every 150 passes for each specimen were shown in Figures (6) to (9). Figure (6) presents the permanent deformation behaviour for BC mix prepared with 60/70 binder. The permanent deformation at the end of the 15,000 cycles is 20.89mm. Figure (7) presents the permanent deformation behaviour for BC mix prepared with CRMB-6%. The permanent deformation at the end of the 15,000 cycles is 15.47mm.
Figure 6. Rut Depth for BC Mix with 60/70

Figure 7. Rut Depth for BC Mix with CRMB 6%

Figure 8. Rut Depth for SMA Mix with 60/70

Figure 9. Rut Depth for SMA with CRMB 6%

Figure 8 presents the permanent deformation behaviour for SMA mix prepared with 60/70 grade binder. The permanent deformation at the end of the 15,000 cycles is 10.41mm. Figure 9 presents the permanent deformation behaviour for SMA mix prepared with CRMB-6% binder. The permanent deformation at the end of the 15,000 cycles is 7.22mm.

The results are shown in Fig. (6 to 9) the SMA mixes are lesser of the permanent deformations after 15000 cycles compared with BC mixes. It can be observed from the table, BC and SMA mixes prepared with CRMB-6% showing good resistance against rutting.

6. Conclusions
Marshall Test results indicated 6% crumb rubber content by weight if normal binder content and optimum binder content for the binder in bituminous mixes is 5.1% & 5.5% by weight of mix is have improved the bituminous mixes. Permanent deformations tests were performed for BC and SMA mixes prepared with 60/70 binder and CRMB. Among both mix types, SMA mixes showing less permanent deformation behaviour as compared with BC mixes. Mixes prepared with CRMB showing good resistance against rutting. Benefits from this study are the scrap tires disposal is an eco-friendly way, reduction in bitumen consumption, no toxic emission and better road to withstand rutting.
References
1. Taher Baghaee, Mehrtash Soltani, Mohamed Rehan Karim 2014 *Construction and Building Materials* 65 487 https://doi.org/10.1016/j.conbuildmat.2014.05.006
2. Imran, Shahid, Majed, Feras F 2016 *Procedia Engineering* 145 1557 https://doi.org/10.1016/j.proeng.2016.04.196
3. Shubham, Anil, Purnima 2017 *International Journal of Sustainable Built Environment* 6 442 https://doi.org/10.1016/j.ijsbe.2017.07.009
4. Nabin Rana Magar 2014 *International Journal of Engineering Trends and Technology (IJETT)* 14 (2) https://doi.org/10.14445/22315381/IJETT-V14P211
5. Utibe J., Johnson A., Feyisayo V., Obioma U. 2017 *Procedia Manufacturing* 7 490 https://doi.org/10.1016/j.promfg.2016.12.051
6. S. K. Palit, K. Sudhakar, B. B. Pandey 2004 *Journal of Materials in Civil Engineering* 16 (1) https://doi.org/10.1061/(ASCE)0899-1561(2004)16:1(45)
7. Cyrille Chazallon 2009 *Computers and Geotechnics* 36 (5) 798 https://doi.org/10.1016/j.compgeo.2009.01.007
8. Okan Sirin, Hong Kim 2008 *Construction and Building Materials* 22 (3) 286 https://doi.org/10.1016/j.conbuildmat.2006.08.018
9. Archilla, A.R. 2006 *Journal of Transportation Engineering* 132 (9) 734 https://doi.org/10.1061/(ASCE)0733-947X(2006)132:9(734)