# Effect of Filler Type and Content on the Rheological Properties of Asphalt Mastics

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**Abstract** This study investigated the influence of various fillers on the rheology and performance of asphalt mastics. Mastics were prepared by mixing a PG70-XX binder with two waste fillers (limestone sludge waste, glass powder) and conventional stone dust filler in three different proportions. Firstly, physical and chemical properties of fillers were determined and then asphalt concrete mixes were designed. Based on their optimum bitumen contents, the filler bitumen ratios were determined and mastics were prepared. The multiple stress creep and recovery (MSCR) test and linear amplitude sweep (LAS) analyses were performed to analyze the behavior of asphalt mastics against rutting and fatigue. In general, the use of waste fillers improved the rheological behavior of mastics in comparison to conventional stone dust mastic. The stiffness of all mastics increased with the filler bitumen ratio. The glass powder mastic displayed superior stiffness at all temperatures and exhibited higher elastic recovery and lower creep compliance.

**Keywords** Asphalt mastic · Filler · Rheology · MSCR · LAS · Sustainability

## 1 Introduction

Asphalt mixes are conventionally made up of aggregates, bitumen and fillers. Fillers are the finest part of aggregates which pass through 75 μm sieve [1]. The homogenous mix of filler and bitumen is usually defined as the mastic. Several studies have observed that the physical and chemical properties of the filler, their physical-chemical interaction with bitumen, and their volumetric concentration in the mix significantly influence the performance of mastic and asphalt mixes [2, 3]. Stone dust, cement, and hydrated lime are being conventionally utilized in asphalt mix composition as fillers since they deliver satisfactory performances in the mix. However, several studies have observed that the solid wastes like bauxite residue [2]; carbide lime [2]; rice straw ash [2] etc. could be beneficially utilized as fillers. This study

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**Table 1** Chosen gradation of asphalt concrete mixes

| Sieve sizes (mm) | 13.2 | 9.5 | 4.75 | 2.36 | 1.18 | 0.6 | 0.3 | 0.15 | 0.075 |
|---|---|---|---|---|---|---|---|---|---|
| Lower-upper limits (%) | 90–100 | 70–88 | 53–71 | 42–58 | 34–48 | 26–38 | 19–28 | 12–20 | 4–10 |
| Adopted gradation (%) | 91 | 74 | 62 | 50 | 43 | 35 | 25 | 14 | 4.0, 5.5, 7.0 |

aimed to investigate the influence of two industrial waste fillers, glass powder (GP) and dried limestone sludge (LS) on the performance of asphalt mastics. These wastes are generated during the cutting and polishing operations of glass and limestone slabs in their respective industries. The results were compared with conventional mastics made with stone dust (SD) as filler.

## 2 Materials and Experimental Investigation

### *2.1 Material*

Coarse and fine dolomite aggregates and PG 70-XX bitumen were utilized in the study. The gradation used to prepare the asphalt concrete mix was chosen as per Indian guidelines [1] (Table 1). SD was utilized as the conventional filler and was collected from a stone quarry in Sonbhadra District (24.46° N, 82.99° E). LS was collected from the dump yard of dimension stone industry located in Kota City (26.91° N, 75.78°). Whereas, GP was collected from the dump yard of a glass factory located in Bhopal City (23.26° N, 77.41° E). Oven dried filler which passes through 0.075 mm Sieve Was utilized in this study.

### *2.2 Characterization of Fillers*

Specific gravities of all fillers were determined as per ASTM D854. Fineness of the fillers was determined by calculating their fineness modulus (FM) values. Particle shape and surface texture was analyzed using scanning electron microscopy (SEM) analysis. Porosity of fillers was determined as per the German filler test [4]. Prevalent minerals in the filler composition were evaluated using X-Ray Diffraction (XRD) investigation. The analysis of Methylene blue values (MBV) of fillers was done as per the EN 933–9 specification to enumerate the harmful clay content and organic matters in fillers. Various results are stated in Table 2.

**Table 2** Properties of various fillers

| Property | GP | LS | SD | Inferences |
|---|---|---|---|---|
| Specific gravity | 2.370 | 2.650 | 2.698 | GP and LS has lower specific gravity and thus occupies larger volume in asphalt mix |
| Methylene blue value (g/kg) | 1.25 | 3.75 | 3.25 | All fillers have low MBV (less than 10) which indicated the presence of lower harmful clay content per unit weight of material |
| German filer value (g) | 75 | 97 | 85 | GP and LS had lowest and highest fractional voids per unit weight respectively |
| Fineness modulus | 4.66 | 3.03 | 5.38 | SD and LS are coarsest and finest filler respectively |
| Primary Mineralogical composition (XRD) | Quartz ($SiO_2$) | Calcite ($CaCO_3$), Quartz ($SiO_2$), Enstatite ($Mg_2Si_2O_6$) | Dolomite ($CaMg(CO_3)_2$), Quartz ($SiO_2$), Ertixite ($Na_2Si_4O_9$) | SD and LS has dolomite and calcite respectively which are water insoluble mineral having good asphalt adhesion. GP had quartz which is associated with poor moisture sensitivity |

## 2.3 Design of Asphalt Concrete Mix

The Marshall mix design procedure was followed as per MS-2 [5] specification to determine optimum asphalt content (OAC) of asphalt mixes. The OAC is considered as asphalt content corresponds to 4% air voids of the mixes. The effective filler bitumen ratio was then calculated and asphalt mastics were designed according to it.

### 2.4 Preparation and Testing of Asphalt Mastics

A total of nine types mastics were designed by mixing GP, LS, and SD fillers with bitumen in three different filler bitumen ratio, which was decided based on effective OAC of the mixes and their filler contents (4, 5.5, and 7%). The filler content was calculated as the percentage of the total weight of aggregates in mix as per the Indian pavement design guideline [1]. The OAC of the mixes are stated in Table 3 along with the corresponding filler bitumen ratio of their mastics. The mixing was done at 163 °C QUOTE using mechanical mixer operating at 2000 rpm for 30 min. The prepared mastics were short term aged using Thin Film Oven as per ASTM D1754 and were used for testing in Multiple Stress Creep and Recovery test. While, for the testing of fatigue life, short term aged mastics were further subjected to long term ageing as per the protocol suggested by [6].

The rheological properties (complex modulus and phase angles) of short term aged mastics were determined using frequency sweep test performed at intermediate temperature (25 °C) and high temperatures (46–70 °C). The spindle of 8 mm gap (with 2 mm gap) and 25 mm diameter (with 1 mm gap) was used for testing at intermediate and higher temperatures respectively. The testing is conducted in strain controlled mode with applied strain is kept equal low enough so that results falls within the linear viscoelastic region. The testing is done at the frequency range of 0.1–100 rad/s to analyze the influence of testing frequency on rheological parameters.

The MSCR test was conducted on short-term aged samples at 64 °C, using a dynamic shear rheometer (DSR) with 25 mm parallel plate in diameter (1 mm gap), in accordance with the AASHTO T 350. During the tests, each sample was subjected to ten consecutive cycles at two stress levels (0.1 and 3.2 kPa) and every cycle underwent one second creep loading followed by a nine-second recovery without loading. The non-recoverable compliance ($J_{nr}$) and the percent recovery (%R) after 10 cycles at 0.1 and 3.2 kPa were studied. The $J_{nr}$ value was calculated as the ratio between the average non-recoverable strain for 10 creep and recovery cycles, and the applied stress for those cycles.

The fatigue failure analysis was carried with Linear Amplitude Sweep (LAS) test as per AASHTO TP 101. This test was done with DSR with a standard geometry of 8 mm parallel plates and a 2 mm thickness gap. It measures accelerated damage of mastic using cyclic loading by linearly increasing load amplitudes (1–30%). The relationship between the number of loading cycles to failure ($N_f$) and the applied initial strain amplitude ($\gamma$) can be expressed by the following equation.

$$N_f = A(\gamma)^{-B} \tag{1}$$

Where A and B are the fitting coefficients.

# 3 Results and Discussions

## 3.1 Performance of Asphalt Mastics

The results of frequency sweep analysis are presented in the form of black diagrams between the complex modulus and phase angle as stated in Fig. 1. Black diagrams of all mastics were found to shift upwards and towards left as the filler content in them were increased. This clearly indicated that the inclusion of filler imparts stiffness and elasticity to the mastics. Mastics prepared with GP displayed higher complex modulus and lower phase angles followed by LS and SD. This implied the higher stiffening action of GP mastics due to their volume in the mixes. It is also observed that SD and LS mastics followed a consistent trend throughout while GP mastic starting deviate from its trend at higher filler contents. This suggested that at higher filler concentration GP mastics deviate from linear viscoelastic region, even when testing is performed at the strain within the linear viscoelastic limits. The mineralogical composition of GP is also different from LS and SD fillers. LS and SD consist of dolomite and calcite in their compositions which enhance bitumen filler adhesion, while GP consisted of quartz whose adhesion behavior with bitumen is debatable. This aspect may also affect the viscoelastic behavior of mastics and needed a detailed further study.

The rutting resistance of mastics was found to increase with the filler bitumen ratio as determined from their decrease in $J_{nr}$ values and the increase in percentage recovery values at both stress levels (Table 3). The GP mastics displayed highest rutting resistance followed by LS and SD mixes. The higher stiffening of GP mastic might be attributed to the higher volume of glass powder at each filler level. Higher rutting resistance of GP mastics might also be due to the angular nature of particles as well as due to their higher porosity. For all the mastics the fatigue lives were

**Table 3** Table displaying various parameters obtained from MSCR test of mastics

| Filler type | Filler content (%) | Name of mastic | Effective filler Bitumen ratio | Percentage volume of filler in the mastic (%) | Jnr at 0.1 kPa ($kPa^{-1}$) | Jnr at 3.2 kPa ($kPa^{-1}$) | % R at 0.1 kPa (%) | % R at 3.2 kPa (%) |
|---|---|---|---|---|---|---|---|---|
| SD | 4 | SD 4 | 0.66 | 19.64 | 1.0839 | 1.2343 | 5.15 | 0.78 |
| | 5.5 | SD 5.5 | 0.98 | 26.23 | 0.7132 | 0.8042 | 5.62 | 0.94 |
| | 7 | SD 7 | 1.38 | 33.98 | 0.5013 | 0.5733 | 6.55 | 1.70 |
| GP | 4 | GP 4 | 0.71 | 23.04 | 0.4819 | 0.5491 | 7.86 | 1.00 |
| | 5.5 | GP 5.5 | 1.01 | 30.48 | 0.2056 | 0.2142 | 13.42 | 1.50 |
| | 7 | GP 7 | 1.46 | 38.26 | 0.0753 | 0.0597 | 28.66 | 6.10 |
| LS | 4 | LS 4 | 0.70 | 20.88 | 0.8668 | 1.0184 | 7.09 | 1.10 |
| | 5.5 | LS 5.5 | 1.06 | 28.55 | 0.5557 | 0.6414 | 5.96 | 1.07 |
| | 7 | LS 7 | 1.45 | 35.36 | 0.2976 | 0.3282 | 10.93 | 2.99 |

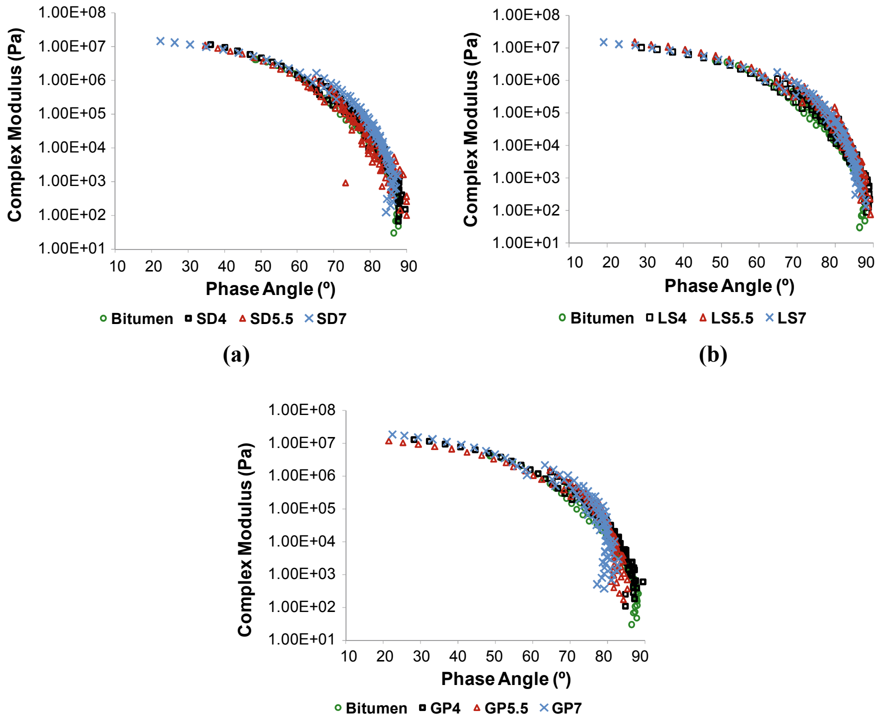


**Fig. 1** **a** Black diagram of SD mastics. **b** Black diagram of LS mastics. **c** Black diagram of GP mastics

found to reduce with the increase in filler bitumen ratio and the increase in strain magnitude (Table 4). The decrease in fatigue lives might be due to the increase in the stiffness of the mastics. In general, the SD mastics have the highest fatigue lives followed by LS and GP mastics. However, LS mastic corresponding to 4% filler exhibited higher fatigue life than SD and GP mastics. It seemed like at lower filler concentration; LS distributed more uniformly than other fillers due to their finest particle size which improved the fatigue resistance of mastics. This effect diminished at higher concentration due to increase in stiffness. The GP mastics were found to be most strain susceptible.

**Table 4** Table displaying various parameters obtained from LAS analysis of mastics

| Type of mastic | A | B | $N_f$ and $\gamma$ relationship | $N_f$ at different strains | | | |
|---|---|---|---|---|---|---|---|
| | | | | 0.1% | 1% | 2.5% | 5% |
| SD 4 | 23903 | 2.50 | $Nf = 23903(\gamma)^{-2.50}$ | 7733532 | 23697 | 2368 | 415 |
| SD 5.5 | 20671 | 2.45 | $Nf = 20671(\gamma)^{-2.45}$ | 5960708 | 20578 | 2156 | 391 |
| SD 7 | 7719 | 2.73 | $Nf = 7719(\gamma)^{-2.73}$ | 4298452 | 7374 | 585 | 86 |
| GP 4 | 13959 | 2.59 | $Nf = 13959(\gamma)^{-2.59}$ | 5554930 | 13904 | 1282 | 211 |
| GP 5.5 | 7012 | 2.70 | $Nf = 7012(\gamma)^{-2.70}$ | 3589537 | 6754 | 556 | 84 |
| GP 7 | 2408 | 2.73 | $Nf = 2408(\gamma)^{-2.73}$ | 1268580 | 2560 | 217 | 33 |
| LS 4 | 27839 | 2.52 | $Nf = 27839(\gamma)^{-2.52}$ | 9398720 | 27993 | 2766 | 480 |
| LS 5.5 | 16440 | 2.51 | $Nf = 16440(\gamma)^{-2.51}$ | 5371132 | 16499 | 1650 | 289 |
| LS 7 | 5758 | 2.64 | $Nf = 5758(\gamma)^{-2.64}$ | 2585007 | 5511 | 477 | 75 |

## 4 Conclusions

This study analyzed the performance of asphalt mastics made with LS and GP as fillers at three filler contents. Both wastes displayed physical and chemical properties synonymous of a good filler. Both GP and LS mastics also displayed higher stiffening and rutting resistance than conventional SD mastics at each filler contents. However, this higher stiffening of these fillers also resulted in relatively lower fatigue lives of their mastics at each filler contents.

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