# The effect of fine aggregate gradation and filler type on the rheological properties of asphalt

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**ABSTRACT** Fine aggregates provide sufficient stability for asphalt mortars, helping to build up good interlocking characteristics and supporting load capacity for asphalt mixtures. Fillers such as ordinary Portland cement and hydrated lime can improve the rutting resistance and moisture susceptibility of the asphalt mixtures. In this study, the influence of aggregate gradation and filler type on the rheological properties of asphalt mortars was evaluated through a series of laboratory tests. Different asphalt mortar samples were fabricated using two aggregate gradations (median and lower level of fine aggregates) and two different fillers (ordinary Portland cement and hydrated lime). Test results showed that the addition of ordinary Portland cement and hydrated lime can stiffen the asphalt mortar, with hydrated lime showing higher stiffness values compared to ordinary Portland cement. Asphalt mortars with a median aggregate have higher $G^*/\sin\delta$ values compared to asphalt mortars with a lower limit aggregate gradation.

**KEYWORDS:** Asphalt binder; Asphalt mortar; Cement; Hydrated lime; Asphalt Rheology
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## INTRODUCTION

Asphalt mortar is a composite material composed of asphalt binder, filler, and fine aggregate. Generally, asphalt mortar fills the voids and spaces between coarse aggregates, holding them together as a cohesive whole (Chen *et al.*, 2019). There are two types of aggregates: coarse and fine. In the production of asphalt mortar, only fine aggregates are used. Elkhalig *et al.* (2012) stated that proper selection of fine aggregate based on its properties can improve the interlocking mechanism between asphalt material particles. Jing *et al.* (2018) also reported that asphalt mortar plays an important role in holding the aggregates of an asphalt mixture together and serves as an adhesive feature between coarser aggregates.

Zhang & Leng (2017) evaluated the effect of aging on the properties of asphalt mortar and quantified its effect on the raveling of porous asphalts. Test results showed that aging of asphalt mortars fabricated with base binder has a more significant effect on the raveling resistance of porous asphalt when compared to those fabricated with Styrene-Butadiene-Styrene (SBS) binder. Woldekidan *et al.* (2010) tested and modeled the responses of various asphalt mortars. Their analysis showed a strong relationship between creep-recovery data and other DSR test results for asphalt mortars.

Pavlatos *et al.* (2018) evaluated the effect of aluminum and steel fibers on the performance of asphalt mortars. It was found that asphalt mortars containing aluminum fibers and steel fibers exhibit induction heating properties. There are several types of fillers commonly used in producing asphalt mixtures, including Ordinary Portland Cement, hydrated lime, limestone dust, and fly ash. The usage of these types of fillers highly depends on the mix design specification and consideration to ensure the filler is suitable for real site conditions. According to Diab & Enieb (2018), the mechanical properties of the asphalt mixtures highly depend on the type and amount of the filler used. Moreover, fillers affect the properties of asphalt mortars. Li *et al.* (2009) reported that the filler type significantly influences the viscosity of asphalt mortars. Woldekidan *et al.* (2013) evaluated the effect of backhouse fine and hydrated lime on the properties of aged asphalt mortars, and results showed that backhouse fines reduce the complex modules at high temperatures. In addition, Zhang *et al.* (2019) investigated the use of fine solid waste in asphalt mortars, and results indicated that asphalt mortar incorporating diatomite and red mud increases the high-temperature properties and adhesion abilities of asphalt mortars. Furthermore, Mistry and Roy (2020) evaluated the effect of two fillers (rice husk ash and fly ash) on the performance of asphalt mortars, and results exhibited that rice husk ash asphalt mortars have better adhesive force than fly ash asphalt mortar. Healing, electrical, and creep properties of asphalt mortars were investigated by Apostolidis *et al.* (2016), García *et al.* (2009), and Xie *et al.* (2014), respectively.

Aggregates can be classified into two groups, coarse and fine aggregates, and their gradation affects the properties of asphalt mortars. Generally, the median line of aggregate gradation between upper and lower limits of standards is used in laboratory works for the fabrication of asphalt mixtures. However, these values can be changed in asphalt plant production procedures. In this research, two different types of aggregate gradation were used to prepare asphalt mortar samples. The asphalt mortars were fabricated according to the lower and median aggregate limit specifications. In Malaysia, the most frequently used fillers to produce asphalt mixtures are Ordinary Portland Cement and hydrated lime. Hence, the physical properties of asphalt mortars containing these fillers were investigated. The aim of this study is to determine the effect of aggregate gradation of these fillers on the rheological properties of asphalt mortars through creep recovery test, dynamic shear oscillatory, softening point, and penetration tests.

## MATERIAL AND METHODS

For this study, Asphalt binder 60/70 from Kemaman Asphalt Binder Company Sdn Bhd was selected. The asphalt binder had a penetration value of 70 mm (ASTM D5) and a softening point of 47°C (ASTM D36). To produce the asphalt mortars, fine aggregates ranging from 75 µm to 425 µm were obtained from a laboratory mechanical shaker. The grading procedure followed the aggregate gradation provided by the Malaysian Public Works Department (PWD) specifications for asphalt mixtures type AC14, as shown in Table 1. Two types of filler, Ordinary Portland Cement (OPC) and hydrated lime (HL), were used for the preparation of asphalt mortars. The specific gravity of OPC and HL were 2.40 and 3.31, respectively. Additionally, there was a filler passing through a 75 µm sieve and retained in a pan. Each OPC or HL was mixed with the filler produced from the pan in the ratio of 90:10.

**Table 1.** Aggregate gradation based on the PWD specifications.

| Sieve Size | Percentage Passing | Median (%) | Mix Design |
|---|---|---|---|
| 20 mm | 100 | 0 | 0 |
| 14 mm | 90 – 100 | 95 | 5 |
| 10 mm | 76 – 86 | 81 | 14 |
| 5 mm | 50 – 62 | 56 | 25 |
| 3.35 mm | 40 – 54 | 47 | 9 |
| 1.18 mm | 18 – 34 | 26 | 21 |
| 425 µm | 12 – 24 | 18 | 8 |
| 150 µm | 6 – 14 | 10 | 8 |
| 75 µm | 4 – 8 | 6 | 4 |

To produce an asphalt mortar of 1200 g mass, Asphalt binder 60/70, fine aggregates ranging in size from 425 um to 75 um (including pan), and OPC and HL filler were mixed together using the Hobart mixer. The correct amount and proportion of these three elements needed to be designed to ensure a consistent and homogeneous asphalt mortar. The optimum asphalt binder content for the asphalt mixture fabricated from the same materials was 5.1%. The composition of the asphalt mortar, containing fine aggregates, filler, and asphalt binder, is illustrated in selected columns in Table 2 for the lower limit and Table 3 for the median limit.

**Table 2.** Lower limit for asphalt mortar mixing design.

| Sieve Size | Percentage Passing by Weight (%) | Percentage Retained (%) | Percentage of Aggregate and binder (%) | Mass of Mortar (g) |
|---|---|---|---|---|
| 20 mm | 100 | - | - | - |
| 14 mm | 90 | 10 | 9.49 | - |
| 10 mm | 76 | 14 | 13.286 | - |
| 5 mm | 50 | 26 | 24.674 | - |
| 3.35 mm | 40 | 10 | 9.49 | - |
| 1.18 mm | 18 | 22 | 20.878 | - |
| 425 μm | 12 | 6 | 5.694 | 308.04 |
| 150 μm | 6 | 6 | 5.694 | 308.04 |
| 75 μm | 4 | 2 | 1.898 | 102.72 |
| Filler | 0 | 4 | 3.796 | 205.32 |
| Asphalt binder (%) | - | - | 5.1 | 275.88 |
| **Total** | **-** | **100** | **22.182** | **1200** |

**Table 3.** Median limit of asphalt mortar mixing design.

| Sieve Size | Percentage Passing by Weight (%) | Percentage Retained (%) | Percentage of Aggregate and binder (%) | Mass of Mortar (g) |
|---|---|---|---|---|
| 20 mm | 100 | - | - | - |
| 14 mm | 95 | 5 | 4.745 | |
| 10 mm | 81 | 14 | 13.286 | |
| 5 mm | 56 | 25 | 23.725 | |
| 3.35 mm | 47 | 9 | 8.541 | |
| 1.18 mm | 26 | 21 | 19.929 | |
| 425 μm | 18 | 8 | 7.592 | 305.99 |
| 150 μm | 10 | 8 | 7.592 | 305.99 |
| 75 μm | 6 | 4 | 3.796 | 152.99 |
| Filler (pan) | 0 | 6 | 5.694 | 229.49 |
| Asphalt binder (%) | - | - | 5.1 | 205.55 |
| **Total** | **-** | **100** | **29.774** | **1200** |

The physical properties of the asphalt binder and asphalt mortars were evaluated using penetration and softening point tests. Additionally, temperature sweep and Multiple Stress Creep Recovery (MSCR) tests were conducted on the samples using a Dynamic Shear Rheometer (DSR). Details of the samples and their tests are illustrated in Table 4.

**Table 4.** Samples and tests.

| Physical Tests | Asphalt binder | Lower Limit Mortar | Median Limit Mortar |
|---|---|---|---|
| Penetration | ✓ | ✓ | ✓ |
| Softening Point | ✓ | ✓ | ✓ |
| **Rheological Tests** | **Asphalt binder** | **Lower Limit Mortar** | **Median Limit Mortar** |
| DSR | ✓ | ✓ | ✓ |

## RESULT AND DISCUSSION

Figure 1 displays the penetration value and softening point of asphalt mortars fabricated with lower limit aggregate incorporated OPC and HL. As shown in Figure 1, the asphalt mortar with OPC has a higher penetration value of 17 mm, while the asphalt mortar with HL has a lower penetration value of 11.3 mm. Furthermore, the softening point of the asphalt mortar with OPC is 70°C, while the softening point of the asphalt mortar with HL is 83°C. These results indicate that the asphalt mortar incorporated with OPC is softer than the one incorporated with HL.

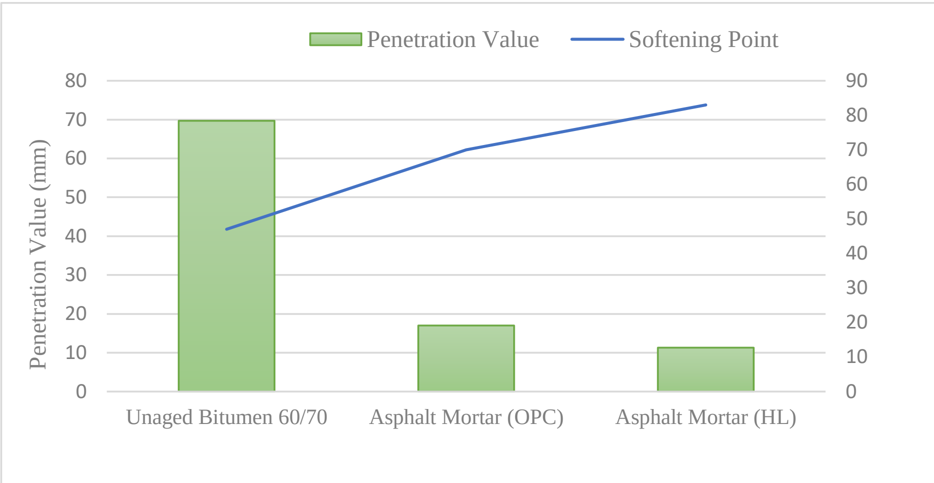


**Figure 1.** Softening point and penetration value of asphalt mortars (lower limit aggregate).

Figure 2 presents the results obtained for asphalt mortars fabricated with median aggregate. As seen in the figure, the asphalt mortar incorporated with OPC had a higher penetration value of 6 mm, compared to the asphalt mortar incorporated with HL, which only had a penetration value of 2 mm. Additionally, the softening point of the asphalt mortar with OPC (95.8 $^{0}$C) was lower than that of the asphalt mortar with HL (107 $^{0}$C). Both samples showed a higher softening point when tested with distilled water, so glycerol was used as a replacement. Glycerol has a higher boiling point compared to distilled water. These results for the median aggregate indicated that the asphalt mortar incorporated with OPC had softer physical properties compared to the asphalt mortar incorporated with HL.

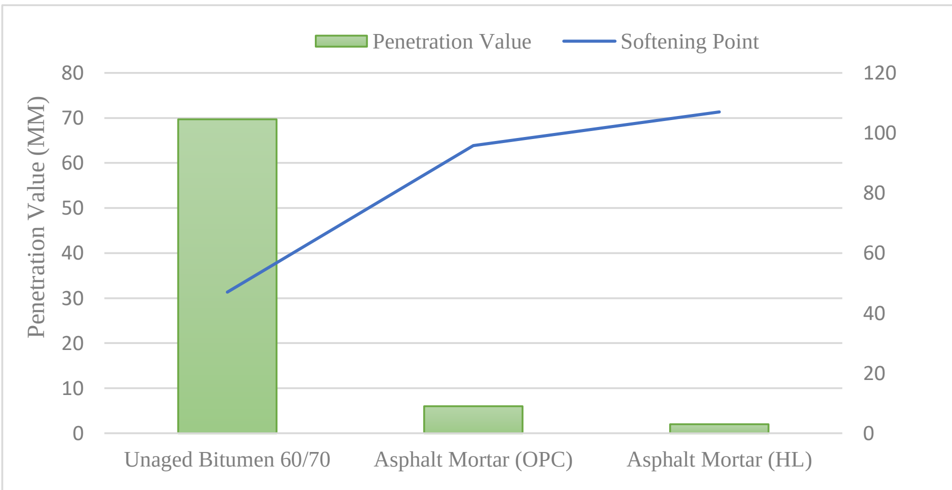


**Figure 2**. Softening point and penetration values of asphalt mortars (median aggregate).

Comparison between the results in Figures 1 and 2 shows that the softening point of asphalt mortars with median aggregate was higher than that of asphalt mortars with lower limit aggregate. The penetration value of asphalt mortars with median aggregate was also lower than that of asphalt mortars with lower limit aggregate.

Figure 3 presents the results of the temperature sweep test conducted on five samples, including the base binder and asphalt mortars fabricated with lower and median aggregate gradation limits. The test aimed to evaluate the rutting resistance of the samples using G*/sin δ. The temperature sweep test was carried out from 46 to 82 $^0$C with a temperature increment of 6 $^0$C according to the Superpave method. As shown in the figure, the base binder exhibited the lowest rutting resistance among all the mortar samples. The rutting resistance of the asphalt binder decreased with increasing temperature. The base binder also had the lowest G*/sin δ values compared to those of the asphalt mortars. At 46 $^0$C, the asphalt mortars incorporated with OPC had a higher rutting resistance for both lower and median aggregate limits compared to the ones incorporated with HL. However, as the temperature increased, the asphalt mortars with HL exhibited higher rutting resistance for both aggregate gradation limits. Higher rutting resistance indicates greater potential or strength to resist rutting.

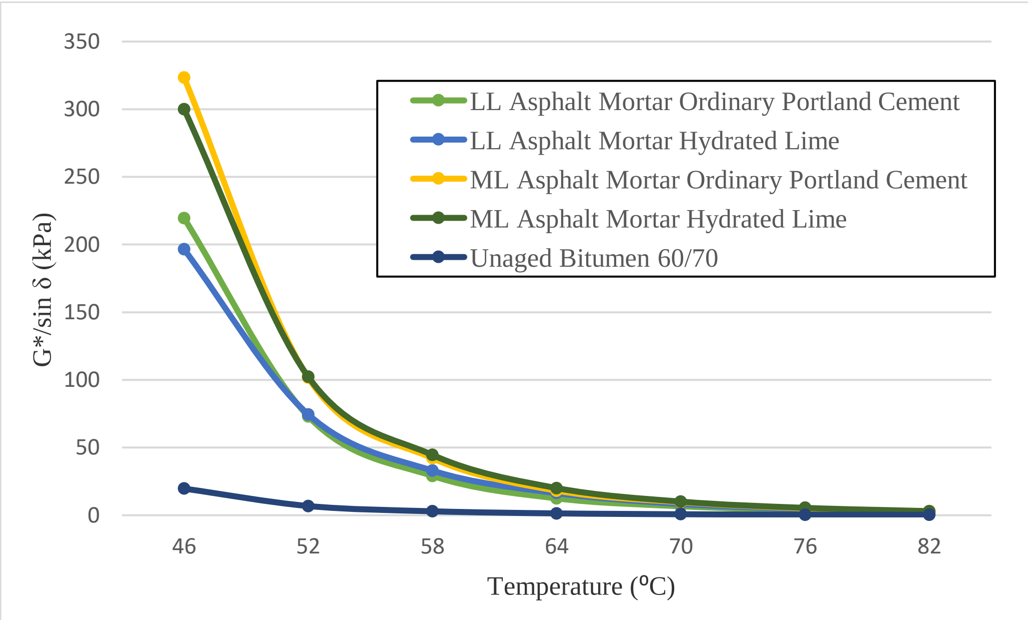


**Figure 3.** G*/sin δ versus temperatures for different asphalt mortars.

The addition of HL and OPC significantly increased the stiffness of the asphalt mortars compared to the base asphalt binder, which is attributed to the filling effects of the fillers. The stiffening effects of the fillers were also observed during the physical tests. Generally, the hydrated lime filler registered a higher rutting resistance ratio compared to the OPC filler. This may be due to a chemical reaction between hydrated lime and binder.

The Jnr values of the base asphalt binder and asphalt mortars are illustrated in Tables 5 and 6, respectively, at stress levels of 0.1 and 3.2 kPa. The test results are related to Jnr values at temperatures ranging from 58 to 70°C with an increment of 6°C. The Jnr is directly dependent on the test temperature and increases with increasing test temperature. In fact, a higher Jnr indicates lower resistance for the asphalt binder towards rutting. From the tables, it is clear that asphalt mortars incorporated with hydrated lime have a lower Jnr, indicating that the incorporation of hydrated lime enhances the rutting resistance of bituminous mixtures. This implies that the incorporation of hydrated lime hardened the asphalt mortars more than ordinary Portland cement (OPC) as a filler. Additionally, the Jnr of asphalt mortars with median aggregate is lower than that with lower limit aggregate. Table 7 shows the percentage recovery (R%) of unaged asphalt binder, lower limit asphalt mortar OPC, lower limit asphalt mortar HL, and median limit asphalt mortar HL from 58 to 70°C at stress levels of 0.1 and 3.2 kPa. Primarily, the results indicate that samples tested at 0.1 kPa exhibit higher R% compared to samples subjected to 3.2 kPa stress level.

**Table 5.** Non-Recoverable Compliance, Jnr, at 0.1 kPa stress level.

| Temperature ($^0$C) | Lower Limit Asphalt Mortar OPC (kPa$^{-1}$) | Lower Limit Asphalt Mortar HL (kPa$^{-1}$) | Median Asphalt Mortar OPC (kPa$^{-1}$) | Unaged Asphalt binder 60/70 (kPa$^{-1}$) |
|---|---|---|---|---|
| 58 | 0.3190 | 0.0470 | 0.0870 | 0.0005 |
| 64 | 0.4060 | 0.1150 | 0.1220 | 0.0001 |
| 70 | 0.9290 | 0.2380 | 0.2100 | 0.0180 |

**Table 6.** Non-Recoverable Compliance, Jnr, at 3.2 kPa stress level.

| Temperature ($^0$C) | Lower Limit Asphalt Mortar OPC (kPa$^{-1}$) | Lower Limit Asphalt Mortar HL (kPa$^{-1}$) | Median Asphalt Mortar OPC (kPa$^{-1}$) | Unaged Asphalt binder 60/70 (kPa$^{-1}$) |
|---|---|---|---|---|
| 58 | 0.2040 | 0.0660 | 0.0520 | 14.31 |
| 64 | 0.4370 | 0.0980 | 0.0780 | 82.94 |
| 70 | 1.0860 | 0.1910 | 0.2000 | 55.62 |

**Table 7.** Percentage of recovery, R, at 0.1 and 3.2 kPa stress levels.

| Samples | 58$^0$C 0.1kPa | 64$^0$C 0.1kPa | 70$^0$C 0.1kPa | 58$^0$C 3.2kPa | 64$^0$C 3.2kPa | 70$^0$C 3.2kPa |
|---|---|---|---|---|---|---|
| Unaged binder | 81.908 | - | 41.900 | -75.107 | -73.611 | -6E+7 |
| LL Asphalt Mortar OPC | 0.192 | - | -22.360 | -40.481 | -24.309 | -989.242 |
| LL Asphalt Mortar HL | 37.900 | 50.907 | 31.108 | -22.027 | -20.710 | 14.341 |
| ML Asphalt Mortar HL | 23.305 | 40.123 | 11.589 | -24.602 | -60.537 | -1127.060 |

## CONCLUSION

Based on the physical properties results, asphalt mortars exhibit more strength compared to the base asphalt binder. It can be concluded that asphalt mortar incorporating hydrated lime has the greatest strength compared to the other samples. The physical test shows that asphalt mortar incorporating hydrated lime has the lowest penetration value and the highest softening point, which is attributed to the stiffening effect of hydrated lime compared to OPC. The rheological characterisation indicated that the addition of fillers stiffened the asphalt binder, and the addition of HL and OPC significantly increased the G*/sin δ value of asphalt mortars compared to the base asphalt binder, indicating higher rut resistance for the asphalt mortar. Moreover, asphalt mortars with median aggregate exhibited higher G*/sin δ value and lower creep compliance value when compared to the asphalt mortars with lower limit aggregate gradation.

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