# Influence of Calcium Carbonate on Performance of Gap-Graded Asphalt Mixes

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**ABSTRACT**

This study aims to enhance the properties of a Gap-Graded Asphalt Mixes (GGAM) by using Calcium Carbonate ($CaCo_3$) with new by-product material Treated Palm Oil Fuel Ash (TPOFA) or Ordinary Portland Cement (OPC) used as a filler. With this purpose, GGAM with conventional binder grade 60/70 were evaluated. The indirect tensile stiffness modulus test (ITS) and resilient modulus ($M_R$) were used to evaluate the effects of using (6%$CaCo_3$ + 2% TPOFA or OPC) on the mechanical properties of GGAM under various test temperatures and subjected to different acceleration ageing conditions were analyzed and interpreted. The result of the experiments indicated that enhancement in the stiffness and water sensitivity resistance is achieved by adding $CaCO_3$ with TPOFA to the GGAM. The results indicate that most aging occurred at the beginning of the pavement life. The resilient modulus is sensitive to temperature_changes. Therefore, as the temperature increases, the resilient modulus decreases. Moreover, it has been recommended to use $CaCO_3$ with TPOFA wherever available to solve the solid waste disposal problem of the environment.

**Keywords:** Gap-Graded Asphalt Mixes, stiffness modulus ratio, acceleration ageing conditions.

## 1. Introduction

Temperature and moisture affect asphalt mixture performance over the service life. Find a quality stone; fracture it into a cubical shape with crushed surfaces, minimize the medium-sized stone and then glue the remaining stones and filler together with rich asphalt binder to give stone-on-stone contact, this recipe called Gap-Graded Asphalt Mixes (GGAM). The paper evaluates the effects of $CaCO_3$ and TPOFA or OPC as a filler on the performance of GGAM. Previous studies have shown that the behaviour of a filler in the asphalt mixture may have different mechanical properties [1-3]. The use of non-conventional filler materials in GGAM is still at an experimental stage in Malaysia. The previous study reported that the use of 5% Palm Oil Fuel Ash (POFA) as mineral filler enhances the properties of asphalt mixture [4]. In another study, was found that can apply POFA as filler percentage rate in the design of asphaltic concrete (ACW 20) [5]. Different variables may affect the $M_R$ results such as temperature, type of loading, frequency and mixture type [6]. Furthermore, the ITS test is used to determine the tensile properties of the asphalt mixture and a higher tensile strength corresponds to a stronger cracking resistance [7-8]. The ageing procedure of asphalt mixture is mostly limited to extend heating on loose material, it may occur through different reactions, recently, researchers use many methods to simulate the actual ageing in service [9-10]. In this study, an investigation on the suitability of $CaCo_3$ with TPOFA used as a filler in GGAM.

## 2. Materials and Methods

### 2.1 Asphalt Binder

Asphalt binder 60/70 penetration grade supplied by Shell Bitumen Company was used. Table 1 summarises the properties of the base binder [11].

Table 1: *Properties of Base Binder [11]*

| Ageing Condition | Property | Values |
|---|---|---|
| Un-aged | Penetration | 63 |
| | Softening Point (ºC) | 48 |
| | Ductility at 25ºC (cm) | 115 |
| | Relative Density at 25ºC | 1.03 |
| | G*/sinδ at 64ºC (Pa) | 1621.40 |
| Short-Term Aged | G*/sinδ at 64ºC (Pa) | 3584.20 |
| Long-Term Aged | G* sinδ at 25ºC (MPa) | 4.51 |

### 2.2 Coarse and Fine Aggregates

The crushed granite geometrically cubical aggregate (GCA) supplied by Kuad Quarry Sdn. Bhd., Penang was used. The basic properties of the aggregate as well as the gradation used which was developed by OPUS International are shown in Tables 2–3 respectively.

Table 2: *Engineering Properties of GCA*

| Property | Test result | Test method |
|---|---|---|
| Coarse Aggregates Bulk Specific Gravity (g/cm$^3$) | 2.624 | AASHTO T85 |
| Absorption (%) | 0.53 | AASHTO T85 |
| Fine Aggregates Bulk Specific Gravity (g/cm$^3$) | 2.575 | AASHTO T84 |
| Absorption (%) | 0.74 | AASHTO T84 |
| Polished Stone Values | 51.10 | ASTM D3319 |
| Flat and Elongated (%) | 13.56 | BS 812 |
| Los Angeles Abrasion (%) | 8.0 | ASTM C131 |
| Aggregate Crushing Value (%) | 16.77 | BS 812-110 |

Table 3: *Aggregate Gradation Developed by OPUS International*

| Sieve Size (mm) | Lower and Upper Limit of Percentage of Passing by Weight (%) | Gradation Used (%) |
|---|---|---|
| 20 | 100 | 100 |

| | | |
|---|---|---|
| 14 | 100 - 90 | 94 |
| 10 | 65-50 | 63 |
| 6.3 | 45-30 | 42 |
| 4.75 | 32-21 | 29 |
| 2.36 | 25-16 | 23 |
| 0.6 | 18-11 | 16 |
| 0.075 | 12-8 | 8 |

## 2.3 Filler

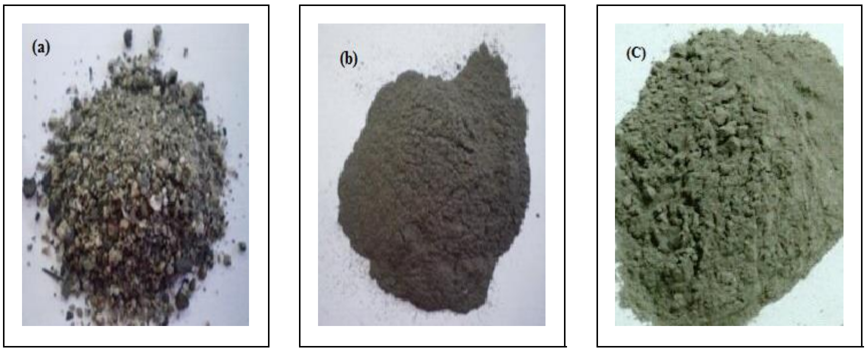
Two filler combinations were used as fillers, namely:

(I) 6% $CaCO_3$+ 2% OPC. (II) 6% $CaCO_3$ + 2% TPOFA.

The specific gravity of fillers was determined according to AASHTO T 133 and the results are shown in Table 4. Several procedures were conducted in Concrete Lab in USM to obtain the TPOFA as shown in Plate 1.

Table 4: *Specific Gravity of Fillers*

| Filler Type | Result (g/cm$^3$) |
|---|---|
| $CaCO_3$ | 2.85 |
| TPOFA | 2.56 |
| OPC | 3.14 |




(a) Raw POFA (b) Grind POFA (c) TPOFA

Plate 1: Obtain the TPOFA

## 2.4 Ageing Procedures

Combinations of 6% $CaCO_3$ with 2% TPOFA or OPC were used as fillers for preparing the GGCP and GGCO respectively, at optimum binder content. After mixing, the trays were kept in a draft oven at 135°C for 4 hours according to AASHTO R30 [12]. The samples were then subjected to ultraviolet radiation (UV) at 85°C for five days that represents 7 to 10 years of the service life [13]. Likewise, other samples were subjected to Environmental Conditioning Chamber (ECC) at 50°C, 70% humidity for 90 days as an alternative accelerated ageing method as shown in Plate 2.

(a) UV

(b) ECC

Plate 2: Different Long-Term Ageing Conditions

## 2.5 Indirect Tensile Strength Test.

ITS test was determined according to ASTM D6931 [13]. Prior to the test, all samples were kept in an incubator for 4 hours at 15°C and subjected to vertical compression load at rate of 50.8 mm/min.

## 2.6 Indirect Tensile Strength Ratio.

ITSR test was performed to evaluate the moisture damage resistance of mixtures, according ASTM D4867 [15]. The test is performed on samples having percentage air voids of 7 ±1%. The test was conducted by subjecting the specimens to compressive loading acting parallel to vertical diametrical plane using testing equipment. Each sample was partially saturated in distilled water using a desiccator under a 635mm-Hg vacuum for 30 minutes at room temperature to achieve 50% - 70% degree level of saturation as shown in Plate 3.

Plate 3: Desiccator

### 2.7 Resilient modulus

$M_R$ test was done to evaluate the extent of change caused by ageing. This test is non-destructive, was performed in accordance with the ASTM D7369 [16].

## 3. Results and Discussion

### 3.1 Indirect Tensile Strength Test

Figure 1 shows ITS test results of GGCO and GGCP. The result indicates that the GGCP exhibits a higher ITS compared with GGCO. The ITS increases with the level of ageing condition. For example, the ITS of the STA sample of GGCP is 5.3% higher than the ITS of un-aged sample. The increase in ITS for the Ultraviolet Radiation (UV) aged sample of GGCP is 12.90%, while for the specimens aged using Environment Conditions Chamber (ECC) is 17.50% superior than the control sample. The results indicate that most aging occurred at the beginning of the pavement life. Regarding the failure mode of the aged sample, it has split into two pieces. This can be explained in terms of the embrittlement material of the aged samples. Based on the test results carried out on the LTA samples, even though the strength of mixture is increased, it has unfavourably lower the fracture energy of mixture.

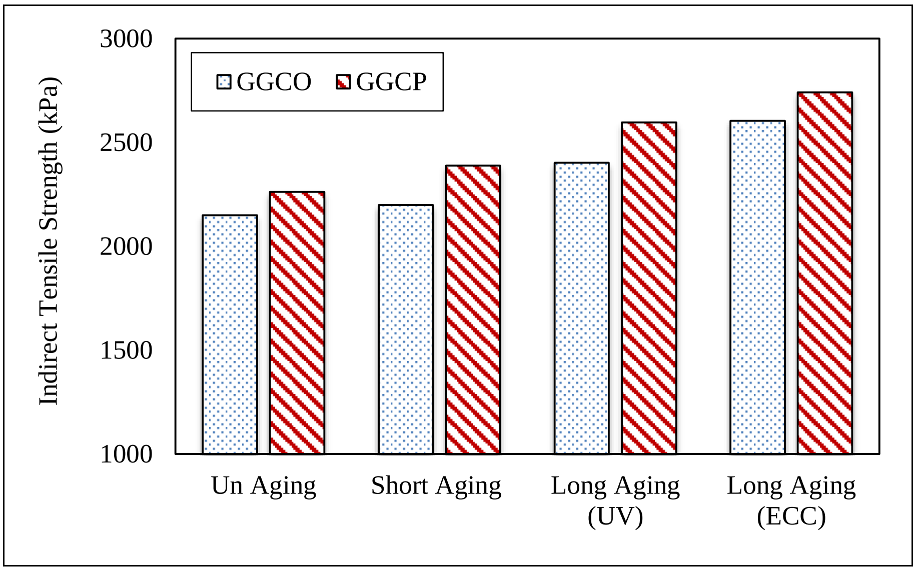



Figure 1: Indirect Tensile Strength Test Results

### 3.2 Mixture Moisture Susceptibility

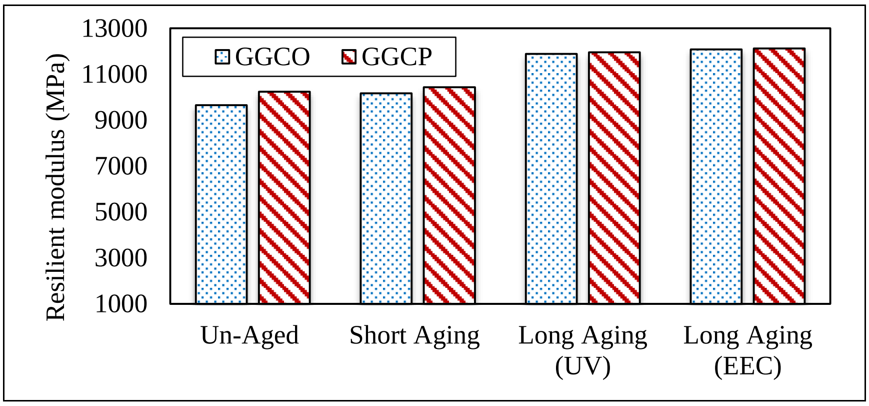
The obtained results of ITSR (%) are presented in Table 5. The ITSR of GGCO and GGCP is higher than 80%, which is the minimum ITSR (%) set by AASHTO T283, the GGCP more resistance against moisture damage compared to GGCO.

Table 5: *Variation of ITSR (%)*

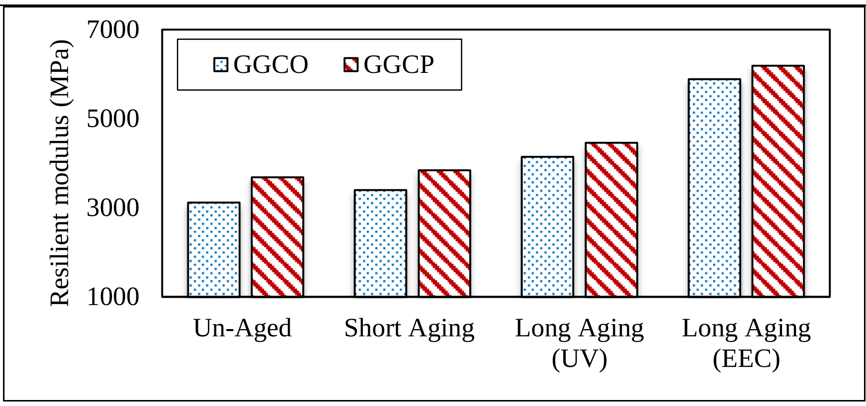
| Mixture | Condition | Max. Load (Pa.s) | D (mm) | h (mm) | ITS (kPa) | ITSR (%) |
|---|---|---|---|---|---|---|
| GGCO | Dry | 10499 | 100 | 71.33 | 937.44 | **87.6** |
| | Wet | 9196 | 99.9 | 71.50 | 821.17 | |
| GGCP | Dry | 10975 | 100 | 66.69 | 1048.10 | **89.7** |
| | Wet | 9925 | 99.99 | 67.27 | 939.86 | |

### 3.3 Resilient Modulus Test

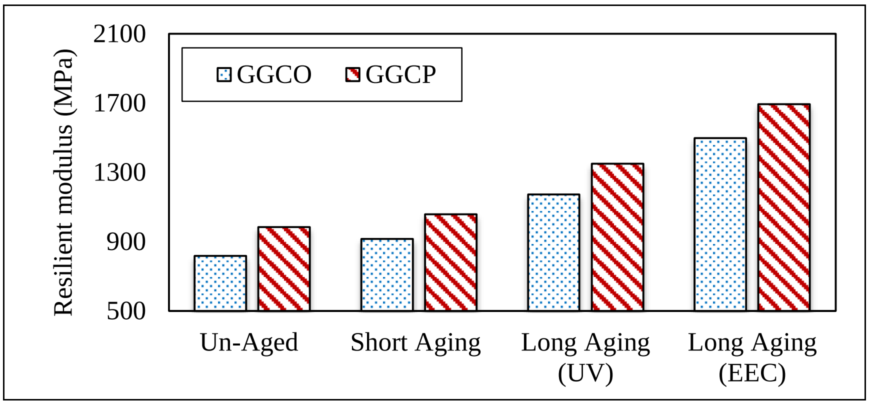
Figure 2 shows $M_R$ values at10°C, 25°C and 40°C. The reported values of $M_R$ represent the average of two identical samples. Aged samples have slightly higher $M_R$ compared to the un-aged samples. Change in temperature from 10°C to 40 °C reduces the $M_R$ by up to 89%. Figure 2 (a) presents the results of $M_R$ against ageing condition at 10°C. For un-aged samples, the highest $M_R$ of 10240 MPa is observed in GGCP. Similar trends are observed in the samples exposed to STA. Also, $M_R$ increases up to 16 % after subjected to LTA. Similar trend is observed for GGCO as shown by an increment up to 20% after subjected to LTA. The same pattern occurs at 25°C and 40°C test temperature as presented in Figure 2 (b) and (c) respectively, where $M_R$ increased when the mixture is subjected to LTA. All GGCO and GGCP mixtures exhibit relatively similar air voids. The resilient modulus is sensitive to the test temperature. When the mixture is conditioned at lower temperature, the viscosity of asphalt binder increased and reduced the strain and ability of the mixture to deform, hence the $M_R$ is higher. On the other hand, when the same sample is exposed to a higher temperature, the strain increases as the viscosity of asphalt binder reduce and decreases the $M_R$. Therefore, the resilient modulus decreases as the temperature increases.




(a) $M_R$ at 10°C




(b) $M_R$ at 25°C




(c) $M_R$ at 40°C

Figure 2: Resilient Modulus Test Results

The ageing index values reported in Table 6 shows ageing is significantly reduced with GGCP, in the case of long-term ageing.

Table 6: Ageing Index for $M_R$ Test

| Samples | Temperature (°C) | Ageing index | | | |
|---|---|---|---|---|---|
| | | Unaged | Short-term ageing | Long-term ageing (UV) | Long-term Ageing(ECC) |
| GGCO | 10 | 1 | 1.05 | 1.23 | 1.25 |
| GGCP | | 1 | 1.02 | 1.17 | 1.19 |
| GGCO | 25 | 1 | 1.10 | 1.33 | 1.90 |
| GGCP | | 1 | 1.04 | 1.21 | 1.68 |
| GGCO | 40 | 1 | 1.12 | 1.43 | 1.83 |
| GGCP | | 1 | 1.07 | 1.37 | 1.72 |

The two-way analysis of variance is used to analyse the impact of filler type, test temperature and ageing condition on the mixture $M_R$. The result in Table 6 indicates that the interaction factor (F * T) has no significant effects. While, from F-value, test temperature is the most significant factor affecting in $M_R$.

Table 7: *ANOVA Analysis of $M_R$*

| Source | SS | Df | MS | F | P-value | Sig. |
|---|---|---|---|---|---|---|
| Corrected Model | 1.28E+09[a] | 23 | 5.57E+07 | 7949.9 | <0.001 | Yes |
| Intercept | 2.18E+09 | 1 | 2.18E+09 | 310840 | <0.001 | Yes |
| A[b] | 4.1E+07 | 3 | 1.37E+07 | 1949.8 | <0.001 | Yes |
| F [c] | 8.46E+05 | 1 | 8.46E+05 | 120.7 | <0.001 | Yes |
| T[d] | 1.23E+09 | 2 | 6.14E+08 | 87552 | <0.001 | Yes |
| A * F | 48151.5 | 3 | 16050.5 | 2.3 | 0.09 | No |
| A * T | 1.21E+07 | 6 | 2.01E+06 | 287.6 | <0.001 | Yes |
| F * T | 19048.4 | 2 | 9524.2 | 1.4 | 0.267 | No |
| A * F * T | 2.73E+05 | 6 | 45514.2 | 6.5 | <0.001 | Yes |
| Error | 3.36E+05 | 48 | | | | |
| Total | 3.46E+09 | 72 | | | | |
| Corrected Total | 1.28E+09 | 71 | | | | |

a. R Squared = 1.000, b. Aging condition، c. Type of Filler, and d. Test Temperature

## 4. Conclusions

The findings of the study show that the addition of combinations of 6% $CaCO_3$ with 2% TPOFA or OPC as fillers enhance the GGAM performance. The results reveal that GGCP exhibited a higher stiffness and higher deformation resistance compared to GGCO. Furthermore, ITSR (%) result is an indication that the GGCP is better compared to GGCO. The results indicate that most aging occurred at the beginning of the pavement life and test temperature is the most significant factor affecting in $M_R$. I recommended to study fatigue behavior of GGAM. Moreover, it has been recommended to use $CaCO_3$ with TPOFA wherever available to solve the solid waste disposal problem of the environment.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