Effect of cement coated aggregates on the creep and deformation characteristics of asphaltic concrete bituminous mixtures

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Abstract

The performance of asphaltic concrete mixtures used in flexible highway pavement is governed to a large extent by the quality of the aggregates used in the mixture. This study presents an investigation into the use of cement coated aggregates in asphaltic concrete mixtures. Its advantages from the point of view of creep and deformation characteristics are investigated in the laboratory and comparison made with mixtures with untreated aggregates using the same gradation and under the same condition of sample preparation and testing. The use of cement treated aggregates in asphaltic concrete mixtures considerably affects the creep behavior of the mixtures, higher stiffness values were obtained for these mixtures as compared to that with the untreated aggregates. Stiffness values increased with an increasing degree in the cement coating. Cement treatment and bitumen content both affected the mixture stiffness in the asphaltic concrete studied. Cement coated aggregate mixtures also showed better deformation resistance as indicated by the lower deformation and wheel tacking rate (WTR) obtained as compared to the control.
Keywords: aggregates, asphaltic concrete, cement coating, creep, deformation.

1 Introduction

Asphaltic concrete mixtures used in flexible pavements contain approximately 90–95% aggregates by weight. The performance of such mixtures is therefore governed to a large extent by the aggregate quality which in turn is a function of

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such factors as mineral composition, surface texture, shape and size of the particles and the type and amount of deleterious matter present.

Most aggregate specifications are written around locally available aggregates. However, problems occur when specifications written for one type of locally available aggregates are used to specify aggregates in another region with different aggregate types. Since the transport of quality aggregates to those locations is usually uneconomical, the use of the local materials in many cases is unavoidable, calling for certain treatments to the aggregates to be made.

In order to satisfy the criteria for aggregate performance, an aggregate treatment method which is practically feasible for improving the locally available aggregates should be investigated. General methods available for this purpose include aggregate blending, aggregate impregnation, coating and chemical treatments (using admixtures).

This study presents an investigation into the use of cement coated aggregates in asphaltic concrete mixtures. The advantages of the cement coated aggregate mixtures were investigated by comparing their laboratory performances to that of the control using the same gradation and under the same condition of preparation and testing.

2 Test methodology and concept of cement coating

Aggregates are regularly subjected to degradation due to loading and environmental conditions. The physical and chemical breakdown of aggregates due to the interaction with water and other aggressive environmental factors has been reported as a potential mechanism contributing to pavement distress [1].

Bayomi [2] suggested that an improvement in mixture strength and resistance to deformation might be gained by improving adhesion of the bituminous binder to the aggregate surface and by increasing the internal friction of the aggregate matrix. Both adhesion and internal friction are largely affected by the surface texture of the aggregates.

Majidzadeh and Brovold [3] suggested that aggregates which have porous and slightly rough surface will promote adhesion by providing for the mechanical interlock between the bitumen and the surface of the aggregates.

Rice [4] has previously suggested that rough surfaces and the irregular shape of the aggregate particles increase adhesion. Rough-textured aggregates not only retard stripping and infiltration but also provide greater area of contact between the binder and the aggregates.

The promotion of adhesion is not difficult to understand from an engineering point of view, it is noticeable that such roughness leads to a considerable increase in the particle internal friction that in turn, modifies the shear strength and increases the load bearing capacity of the bitumen-aggregate system.

3 Materials used in investigation

3.1 Coarse aggregate

The coarse aggregate was crushed limestone prepared from three nominal maximum sizes: 14mm, 10mm and 5mm which is angular and rough in surface texture.

3.2 Fine aggregate

The fine aggregates used was crushed gritstone composed mainly of siliceous sedimentary rock, dark grey in colour, angular in shape and rough in surface texture.

3.3 Mineral filler

A certain amount of filler is necessary in bituminous mixtures to fill a portion of the space between the aggregate particles and hence contribute to the increased density and strength. In this study, the mineral filler used was limestone powder.

The properties of the aggregates and filler material used in this study are given in Table 1.

Table 1: Properties of aggregates used.

MATERIAL	PROPERTY	MEASURED VALUE
Coarse Aggregate	Bulk Specific Gravity	2.658
	Bulk Specific Gravity (SSD)	2.672
	Apparent Specific Gravity	2.712
	Water Absorption	0.706
Fine Aggregate	Bulk Specific Gravity	2.714
	Bulk Specific Gravity (SSD)	2.732
	Apparent Specific Gravity	2.775
	Water Absorption	0.655
Mineral Filler	Specific Gravity	2.724
Portland Cement	Specific Gravity	3.160

3.4 Bitumen

The bitumen used in this study was 100pen grade bitumen. The properties of the bitumen used are given in Table 2.

3.5 Combined aggregate gradation for asphaltic concrete mixes

The aggregate gradation used in this study was achieved by separating all aggregates into seven fractions based on the relevant British Standard sieves: 10mm, 6.3mm, 5mm, 2.36mm, 1.18mm, 0.06mm and 0.075mm. For each specimen, the calculated mass of each nominal size fraction was subsequently recombined to obtain the desired grading characteristics. The gradation of the aggregate used in this study is given in Table 3 and shown graphically in Figure 1.

Table 2: Properties of 100pen Grade Bitumen used.

Property	Measured Value
Penetration (1/10mm, 100gm, 5sec.) Softening Point (Ring and Ball) °C Specific Gravity at 25°C Penetration Index	 98 44.4 1.026 -1.045

Table 3: Gradation of aggregates used.

BS Sieve Size (mm)	Percentage Total Passing (%)	Percentage Mass Retained (%)	Percent Total Mass Retained (%)
14.00	100	0.00	0.00
10.00	91.97	9.03	9.03
6.30	77.42	13.55	22.58
5.00	62.37	15.05	37.63
2.36	49.82	12.55	50.18
1.18	40.86	8.96	59.14
0.60	26.20	14.66	73.80
0.075	10.00	16.20	90.0

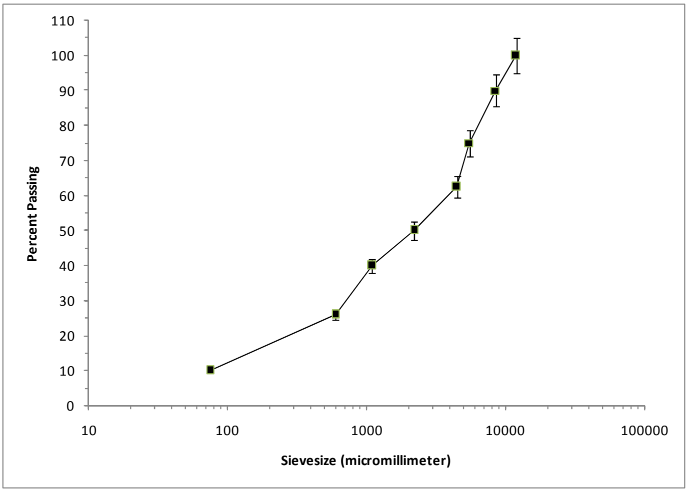

Figure 1: Aggregate gradation used in this study.

3.6 Preparation of cement coated aggregates

The concept of cement coating starts with the assumption that the aggregate particles are to be coated by a hydrated cement film which is thick enough to permanently shield the surface of the aggregate but not so thick as to cause sticking amongst particles and form concrete lumps. To achieve this objective, the following three parameters are first considered to be determined at their optimum.

a. Cement content needed for efficient coating of the aggregates with a uniform cement film.
b. The water/cement ratio required for the optimum coating process and hydration of the cement.
c. Minimum hydration time needed to achieve a permanent bond of the cement paste coating film onto the aggregate surface.

Two methods of coating were investigated: coating of the total combined gradation of the aggregate mix and coating of the individual size fractions of coarse aggregate separately. In both methods, the aggregates were sieved before and after coating to detect any changes in gradation as a result of the coating process. The former method however failed to satisfy the job specification requirements for gradation. A particular difficulty was a significant and uncontrollable change in the aggregate gradation after treatment.

This study indicated two extreme and identifiable state of coating within which successful treatments were attainable. At the lower levels of water and cement contents, the added cement fails to adhere permanently to the surface of the particles, resulting in poorly coated aggregates and higher fines content when the aggregates are re-sieved. On the other hand, at higher levels of water and cement; the finer fractions of the aggregates started forming weakly cemented lumps; thus creating a coarser gradation that lacked the finer contents. This condition in general, results in the loss of a continuous gradation of the mixtures when compared to mixtures containing uncoated aggregates.

In view of the above, the later method was selected in this study. Sieving carried out in the laboratory did not detect any changes in the gradation after coating. Two levels of coating were investigated i.e. at 3% and 5% of cement content by weight of the aggregates. Tests results showed that a water/cement ratio of 0.55 was optimum. As suggested by Bayomi [2], a minimum curing period of 24 hours was adopted in this study to allow for cement hydration and to ensure permanent bond of the cement film onto the particle surface.

3.7 Laboratory coating techniques

There are two techniques of coating the aggregates namely external and internal coating. The external coating of the aggregates results in the aggregate surface being covered with a continuous film of material. This film should contain a minimum amount of flaws as these flaws would permit access; especially by water; to the aggregates. Internal coatings are coatings of the internal pore system, where the total porosity of the aggregates may not be filled with the coating material [5].

In this study, the first technique was employed as in terms of effectiveness, this method is more economical and practically more feasible for application in asphaltic concrete bituminous mixtures. The process of cement coating the aggregates was performed on a small scale in the laboratory using a concrete mixer. Compaction of the specimens were done by the Gyratory Testing Machine (GTM).

4 Effect of cement treatment on the creep properties

Tests conducted to study the creep properties of the mixtures were carried out using the static creep apparatus. Static or creep stiffness (S_c) calculated in this study refers to the relationship between stress and strain suggested originally be Van der Poel [6] in the form:

$$S_c(t,T) = \frac{\sigma}{\varepsilon} \tag{1}$$

where

$S_c(t,T)$ - mix stiffness at a particular time and temperature
σ and ε - axial stress and strain respectively

Figure 2 shows the creep test results plotted in the form of mix stiffness (S_c) versus bitumen content. In general, the stiffness of the mixtures decreases with increasing bitumen content. In addition, there appears to be optimum bitumen content for maximum stiffness. Initially the stiffness increases as the bitumen content increases and then decreases with further increase in bitumen content. This may be attributed to the fact that when the percentage of bitumen increases, the mixtures became more plastic and hence lower stiffness values were obtained.

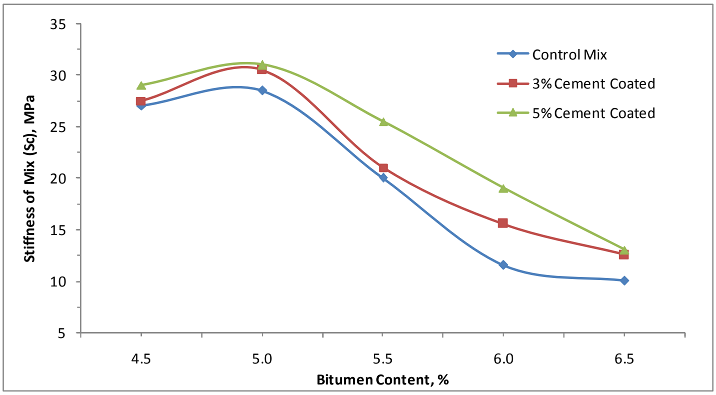

Figure 2: Stiffness of mix (Sc) versus bitumen content for mixtures with different percent of cement coating.

Mixtures made with cement coated aggregates possess higher stiffness values when compared with the control mix. The stiffness values increase as the level of cement coating in the mix increases.

The test results indicate that cement coating appears to stiffen the mixtures as was reflected by the reduction in the flow values for all the treated mixes. It is believed that the stiffening effect of the cement on the bitumen and the increase in the surface roughness of the aggregates after pre-coating with cement, played an important role in improving the stiffness values of the mixtures.

Another way of expressing the creep results is to plot log Smix versus Sbit curve. This represents a basic material characteristic for assessing mix resistance to permanent deformation. Figure 3 shows an example of a typical Smix-Sbit plot for a bitumen content used in this study. The Smix values were determined by dividing the stress by the strain, calculated from the static creep test measurements, whereas the Sbit parameters were determined using the nomograph developed by Van der Poel [6]. It can be seen that the Smix tend to decrease with decreasing Sbit and as can be expected, the treated mixtures increase aggregate interlock which resulted in increased stiffness values of these mixtures, indicating higher resistance to deformation.

5 Resistance to deformation

The determination of the resistance to deformation in this study was carried out using the simulative Wheel-tracking machine. Mixtures containing optimum bitumen content by weight of mix, were tracked at 45°C with a reciprocating motion having a frequency of 42 passes per minute. Additional specimens containing bitumen contents of 0.5% above and below the optimum value were also tracked at the same condition of test as above.

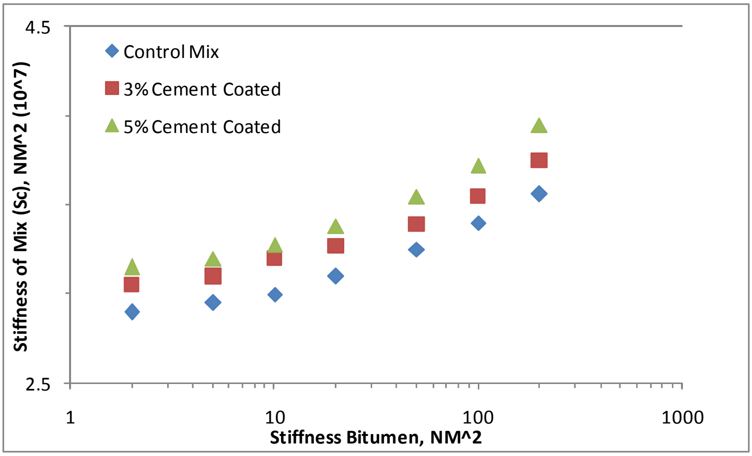

Figure 3: Stiffness of mix (Sc) versus stiffness of bitumen for mixes with different percent of cement coating.

From the deformation-time curves, the asymptotic rate of increase in track depth was determined and expressed in units of mm/hour. The following relationship was used to calculate the wheel-tracking rate from the test:

$$WTR = \frac{D_{45} - D_{30}}{T_{45} - T_{30}} \tag{2}$$

where

WTR	- wheel tracking rate (mm/hr)
D	- cumulative deformation (mm)
30 and 45	- loading time in minutes

An example of the effect of load applications on the rut depth of an asphaltic concrete mixture is shown graphically in Figures 4 and 5. It can be seen that the rut depth increases with increasing number of load applications. The rate of increase is rapid up to approximately 2000 wheel passes after which the relationship between rut depth and load applications become relatively linear.

The bitumen content seems to be a factor contributing to the mix resistance to deformation. Figure 6 presents a relationship between wheel-tracking rate and bitumen content for all the mixtures studied. In general, the wheel tracking rate increases with increasing bitumen content. This can be explained by the fact that at high bitumen contents, the voids in the aggregate structure starts to become overfilled with bitumen. The excess bitumen acts as a lubricant, destroying the internal friction and therefore drastically reducing the resistance to deformation.

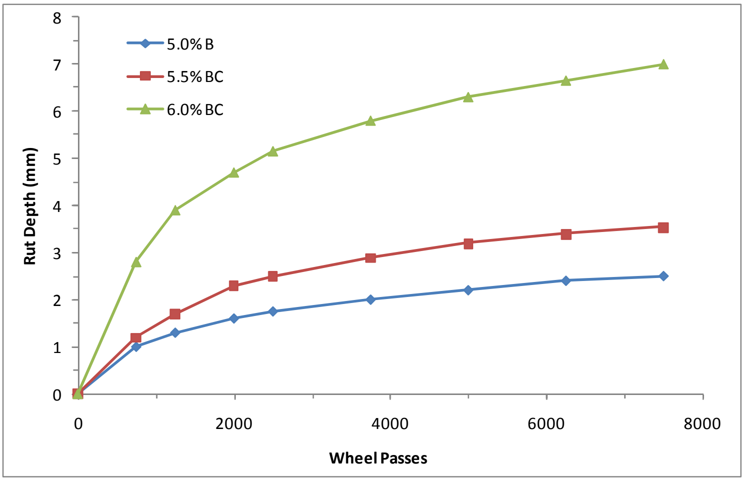

Figure 4: Relationship between load application and rut depth for mixes with different binder content.

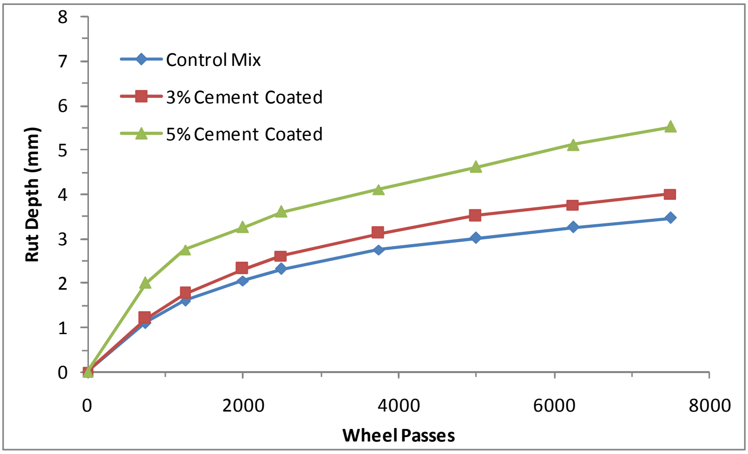

Figure 5: Relationship between load application and rut depth for mixes with different percent of cement coating at each optimum bitumen content.

The above finding is in conformity with Jacobs [7] who found that increasing the bitumen content by 1.5% above the optimum produces an increase in the wheel-tracking rate 2.5 times greater than that at the optimum bitumen content. Bolk and Van der Loo [8] also found that the bitumen content has a substantially greater effect that the filler content on the deformation resistance. Rutting (deformation) decreases with increasing bitumen content.

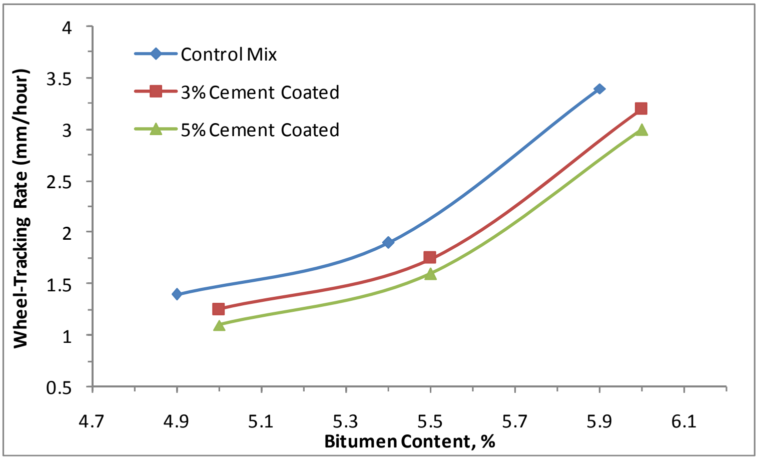

Figure 6: Relationship between wheel-tracking rate and bitumen content.

Figures 4 and 5 also show that mixtures containing cement coated aggregates present better resistance to deformation, which is indicated by the lowest values of deformation and wheel-tracking rates obtained compared to mixture made with untreated aggregates. This is believed to be due to the increase in the surface roughness of the aggregates after the cement coating which in turn resulted in better interlocking amongst the aggregate particles. This will help improve the mixture resistance to deformation.

6 Conclusion

Based on this study, the following conclusions can be made:

1. Bitumen content was found to be a factor that contributes to the resistance of asphaltic concrete mixtures to deformation. Generally increasing the bitumen content resulted in a reduction in resistance to deformation.
2. A good relationship was found between stiffness of the mix and the stiffness of bitumen. The stiffness of the mix tended to decrease with decreasing stiffness of bitumen. Cement treatment and bitumen content both affected the mix stiffness values in the asphaltic concrete mixtures studied.
3. The treated mixes attained the highest stiffness values than the control mix. The stiffness values increased with increasing degree of cement coating.
4. The mixtures containing the cement coated aggregates showed better resistance to deformation which was indicated by the lower deformation and wheel-tracking rate (WTR) values obtained for the cement treated mixture as compared to the control mix.

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