Asphalt Concrete Mixtures Made with Cement-Coated Aggregates

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High-quality asphaltic mixtures for pavement construction in Kuwait are produced by using local aggregates with or without a treatment consisting of 1-2 percent of hydrated lime to improve adhesion and enhance resistance to stripping. In recent years, a third type of mix has been introduced in which the local aggregate is coated with about 4 percent of its weight of portland cement, allowed to hydrate, and then used conventionally in the asphalt plant. The merit of the cement-coated aggregate mix is investigated by comparing its laboratory performance with that of both the untreated mix and the hydrated lime-treated mix, all at the same gradation and under the same conditions of preparation and testing. The properties compared included stability, compactibility, resistance to water action, and dynamic response. Three levels of coating with cement (4.9, 6.3, and 8.1 percent) were considered. The findings indicated that the major advantage of using cement-coated aggregates in hot climates is the production of densely graded mixes of higher stability and lower potential for bleeding. The resistance of these mixes to water is as high as those treated with hydrated lime; the index of retained strength after immersion is almost 100 percent. In addition, cement-coated aggregate mixes showed lower susceptibility of stiffness to temperature at a low frequency of loading, with higher values of stiffness in the higher-temperature range.

Owing to the rapid rate of development in the State of Kuwait in recent years, a significant part of the country's road network was completed during the relatively short period of time since 1975. Unfortunately, the active program of road construction during this period allowed little opportunity to adequately monitor and collect feedback on actual pavement performance. The lack of such information made it impossible to identify accurately and at an early stage those forms of pavement distress that proved subsequently to be often encountered in the hot and dry climate of the region.

In recent years, such forms of distress as surface corrugations, excessive permanent deformation in the wheel paths, and fatting-up have significantly increased, and apparently there are no effective remedial measures available to the road authorities. This situation urgently called for a long-term solution to the problem. The initial diagnosis stressed the weakening effect of the very high temperatures in the asphalt pavement layers during the long summer season. These temperatures obviously caused large reductions in stability, which permitted plastic flow, and stiffness, which meant lower load spreadability. An obvious need has therefore arisen for the development of improved asphaltic mixtures with lower susceptibility to temperature.

Experimentation by using a coating of local aggregates with portland cement for the production of high-quality asphaltic mixtures started in early 1977. It was intended to improve the general mix performance by enhancing the frictional component of stability and the aggregate-binder affinity and adhesion. The aggregate was treated with about 4 percent of its weight of portland cement with sufficient water to satisfy the requirements of aggregate absorption and cement hydration. The treated aggregate was then allowed to cure for two days to form a coating of hydrated cement before it was used conventionally in the asphalt plant. The encouraging results of this technique led to the construction and monitoring of a 500-m trial section on a major road in Kuwait. The short-term performance of this section was judged by road authorities to be very satisfactory, and the technique was subsequently introduced into the construction specification of the major road network (1).

This paper is concerned with the laboratory performance of asphaltic mixes made with cement-coated aggregates compared with the corresponding performance of two conventional mixes of the same gradation and type of parent aggregate: an untreated mix and one (of wide local application) treated with 1 percent of hydrated lime. The effects of cement-treating the aggregates and the degree of this treatment on the stability, compactibility, water resistance, and dynamic response of the resulting asphaltic mixtures were investigated.

ROLE OF CEMENT IN ASPHALTIC MIXTURES

The concept and practice of coating aggregates for use in asphaltic mixes is not new. In general, the process has been employed in an effort to ensure durable adhesion in the bitumen-aggregate system. Portland cement has been used primarily as a filler in warm-mixed bituminous mixtures to prevent stripping of the binder from previously dried aggregate; it has also been used to enhance the coating of wet aggregate with bitumen or tar (2).

Schmidt, Santucci, and Coyne (3) studied the effect of adding 1.3 percent and 3 percent of Type 1 portland cement in an attempt to improve the slow development of strength of emulsion-treated mixes. The cement was added to the aggregate at the time the asphalt emulsion was incorporated. It was concluded that mixes treated in this way cured faster, developed a high modulus of resilience (M_r) more rapidly, and were more resistant to water damage. Flexural fatigue (controlled-stress) experiments showed, however, that these treated mixes have less fatigue resistance than do similar mixes without cement. Terrel and Wang (4) had previously shown also that the rate of development of M_r in emulsion-treated mixes is greatly accelerated by the addition of cement.

Head (5) has reported the results of research on cement-modified asphalt cold mixes. He found that the addition of cement had a very significant effect on mix stability; addition of 1 percent produced an increase in stability of 250-300 percent over that of untreated samples. Specimens without cement immersed in water after stability tests disintegrated after 24 h, whereas cement-treated samples displayed no deterioration. The addition of 1 percent of cement also had the effect of doubling the flow values, but with 2 percent of cement these values were observed to decrease as the samples became more rigid. Results of the immersion-compression investigation indicated not only that moisture or prewetting of the aggregate is necessary to activate the cement but also, possibly, that the moisture available in the emulsion is not effective for hydrating the cement.

Schmidt and Graf (6) have shown that dramatic water resistance and with some aggregates a large increase in the dry M_r of the hot mixes were imparted by adding the cement and lime as a slurry to the aggregate 24 h before the hot mix was made.

Figure 1. Aggregate gradations used.

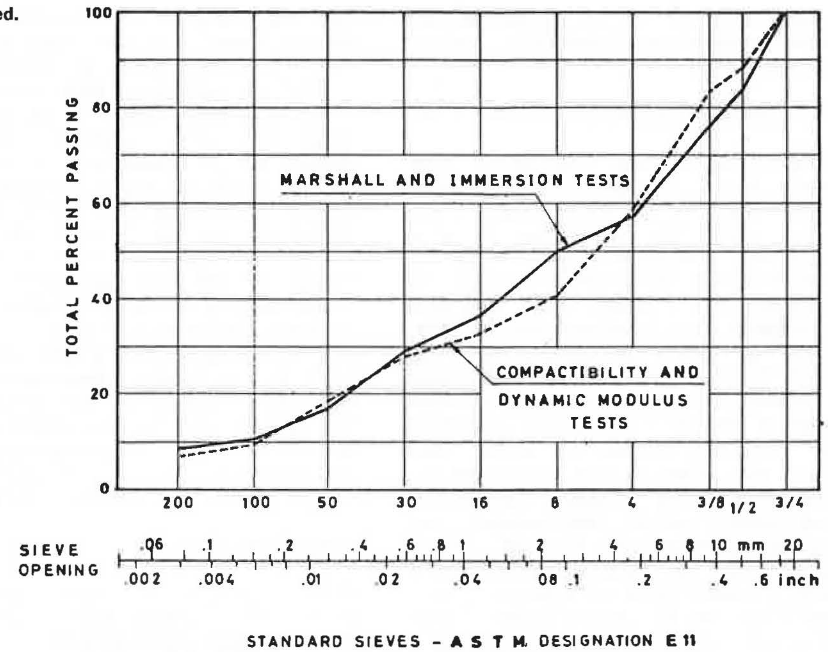


Table 1. Percentages of cement for coating aggregates at three levels.

	Cement (%)				
	Nominal Maximum Size or Type[a]				
Level of Coating	19 mm	9.5 mm	Natural Sand	Crushed Sand	Avg
Light	2.5	4.5	6	7	4.9
Medium	2.5	4.5	9	10	6.3
Heavy	2.5	4.5	14	13	8.1

[a]The ratios of water to cement were 0.65, 0.45, 0.35, and 0.35, respectively.

Table 2. Properties of materials used.

Property or Test	Asphalt Cement	Aggregate: Natural Sand	Aggregate: Crushed Sand	Aggregate: Coarse Aggregate
Penetration (25°C, 100 g, 5 s)	63			
Flash point (Cleveland Open Cup, °C)	260			
Solubility in trichloroethylene (%)	99.5			
Viscosity at 60°C (poises)	3300			
Bulk specific gravity[a]		2.64	2.67	2.52
Sodium sulfate soundness[b] (%)		9	6	-
Sand equivalent[c]		58	41	-
Los Angeles abrasion[d]		-	-	23

[a]AASHTO T84/T85. [b]AASHTO T104. [c]AASHTO T176. [d]AASHTO 96.

EXPERIMENTAL PROGRAM

Three different tests were carried out on compacted specimens of the untreated, hydrated lime-treated, and cement-coated aggregate mixes. These were the Marshall test (AASHTO T245), the immersion-compression test (AASHTO T165), and the dynamic-modulus test (ASTM D3497). Marshall tests were planned in two series to investigate the stability and the compaction of the different mixtures.

Previous work by Daoud (7,8) at the Road Research Center in Kuwait has shown that the optimum coating (in terms of the uniformity of distribution of the added cement among different-sized fractions of the treated sand) is usually achieved at 11-15 percent of cement, depending on a number of material and processing variables (including aggregate type and gradation, water/cement ratio, etc.). This is believed to be a range that is too high to prove economically feasible for many applications. It was therefore considered necessary to determine the effect on asphalt mix properties of using aggregates coated with lower percentages of cement. Three levels of cement treatment were selected and the resulting coatings were identified as light, medium, and heavy (Table 1).

In order to reduce sources of material variability, the aggregate gradation used was fixed as shown in Figure 1. This was done by sieving all the aggregates, untreated or cement-coated, into nine size fractions (by using sieve Nos. 1/2, 3/8, 4, 8, 16, 30, 50, 100, and 200) and recombining these fractions on a weight basis to produce the test gradation.

Materials

Table 2 presents the results of tests on the materials used in this study. The asphalt cement is a 60/70 penetration grade produced from refining the local crude; it conforms to AASHTO M20.

The coarse aggregate is all of the crushed type, prepared from two nominal maximum sizes: 19 mm and 9.5 mm. The crushed aggregate is generally produced from hard and dense igneous rock excavated originally from watercourses that can be identified in the desert. The degree of crushing is such that more than 80 percent by weight of the aggregate particles had at least one fractured face.

The fine aggregate is a blend of 60 percent crushed and 40 percent natural sand. The natural sand is fine and evenly graded and consists of about 90 percent silica with some calcium carbonate.

The mineral filler used is a limestone dust that conforms to AASHTO M17. Both the filler and the hydrated lime have more than 75 percent of material passing sieve No. 200. Whenever the hydrated lime was used in the asphaltic mixes, it was added to the aggregate as a slurry and mixed thoroughly before being heated for hot-mix production.

Preparation of Cement-Coated Aggregates

The process of cement-coating the aggregates was performed on a small scale in the laboratory by following the routine applied by local road contractors on a large scale and according to the Kuwaiti road construction documents (1). A 125-L concrete mixer was used for coating 50-kg batches of aggregates. The natural sand, crushed sand, and two sizes of coarse aggregate were treated with cement independently. (Table 1 shows the proportions of cement and water used in coating the four aggregate components.) The natural moisture content of the aggregate was determined in advance and was included in calculating the required amount of water for treatment. The cement was added to the aggregate in the mixer, and after 30 s of dry mixing, the proper amount of water was slowly added. Wet mixing was continued for 90 s, after which the treated aggregate was heaped on a concrete floor, covered with polyethylene sheet to prevent loss of moisture, and left to cure for at least 48 h. After curing, the aggregate was air-dried at room temperature and sieved into fractions.

Testing

Stability

Figure 2 shows the program adopted for determining and comparing the Marshall stability of the different mixes. It was observed during the work that under the conditions of equal compaction effort and gradation, specimens made with heavily coated aggregates produced higher voids than did similar specimens made with lightly coated aggregates. This called for an additional comparison of mix stability on the basis of equal compacted voids. In order to obtain approximately equal voids in specimens of different treatments with the same compactive effort and gradation, an adjustment was made to the proportions derived from aggregates of several sizes used in preparing these specimens. The crushed fraction between sieves No. 4 and No. 8, for example, can be obtained either wholly from a crushed sand or wholly from 9.5-mm nominal maximum-sized aggregate or from the two materials in any ratio. Although they have the same size, the two fractions differ in particle angularity (due to the characteristics of the crushing process), which influenced the content of voids in the compacted specimens produced.

Compactibility

Compactibility was investigated by comparing the state of densification of otherwise identical Marshall specimens prepared for each mix at two different levels of compaction: 50 blows and 75 blows on each end. The specimens were prepared at the optimum asphalt content that corresponded to the type of mix and level of compaction used. The resulting bulk density, void content, voids in the mineral aggregate (VMA), and percentage of voids filled with bitumen were determined for each condition from three independent tests.

Water Resistance

The susceptibility of the mixes to the action of water was evaluated at two levels of cement treatment, light and heavy (Table 1), and two levels of filler content, 8 and 10 percent. Limestone dust was added to the aggregate to bring the fraction passing sieve No. 200 to the required level. Hydrated lime, when added, was regarded as part of the filler content.

The optimum asphalt content for each case was first determined by the Marshall design method by using a compactive effort of 75 blows on each end. This asphalt content was then used in preparing the cylindrical specimens for the immersion-compression test (AASHTO T165). The alternative procedure in which the immersed specimens are kept in water for 24 h at 60 ± 1°C was adopted.

Figure 2. Program for testing effect of type and degree of treatment on stability.

BASIS OF COMPARISON	MIX TREATMENT: No Treatment	Hydrated Lime	Cement[2]: Light	Medium	Heavy[1]
Similar Aggregate Characteristics	X	X	X	X	X
Equal Compacted Voids	-	-	X	X	

1) this mix satisfies both criteria for comparison

2) see table 1

Table 3. Results of Marshall stability tests.

Type and Degree of Treatment	Aggregate Proportions (%): Nominal Size (mm): 19	9.5	Sand: Crushed	Natural	Limestone Dust	Properties of Compacted Mix[a]: Optimum Asphalt (%)	Marshall Stability Ratio (%)	Bulk Density (g/cm³)	Void Content (%)
Untreated	28	20	30	14.5	7.5	4.00	100	2.37	3.1
Hydrated lime, 1 percent	28	20	30	14.5	7.5	4.25	109	2.36	3.1
Cement:									
Light	28	20	30	14.5	7.5	4.50	104	2.40	3.4
Medium	28	20	30	14.5	7.5	4.50	109	2.36	4.2
Heavy	28	20	30	14.5	7.5	4.50	124	2.35	4.9
Light	30	22.5	27	14	6.5	4.50	92	2.33	5.0
Medium	30	20	27.5	15	7.5	4.25	111	2.35	4.7
Heavy	28	20	30	14.5	7.5	4.50	124	2.35	4.9

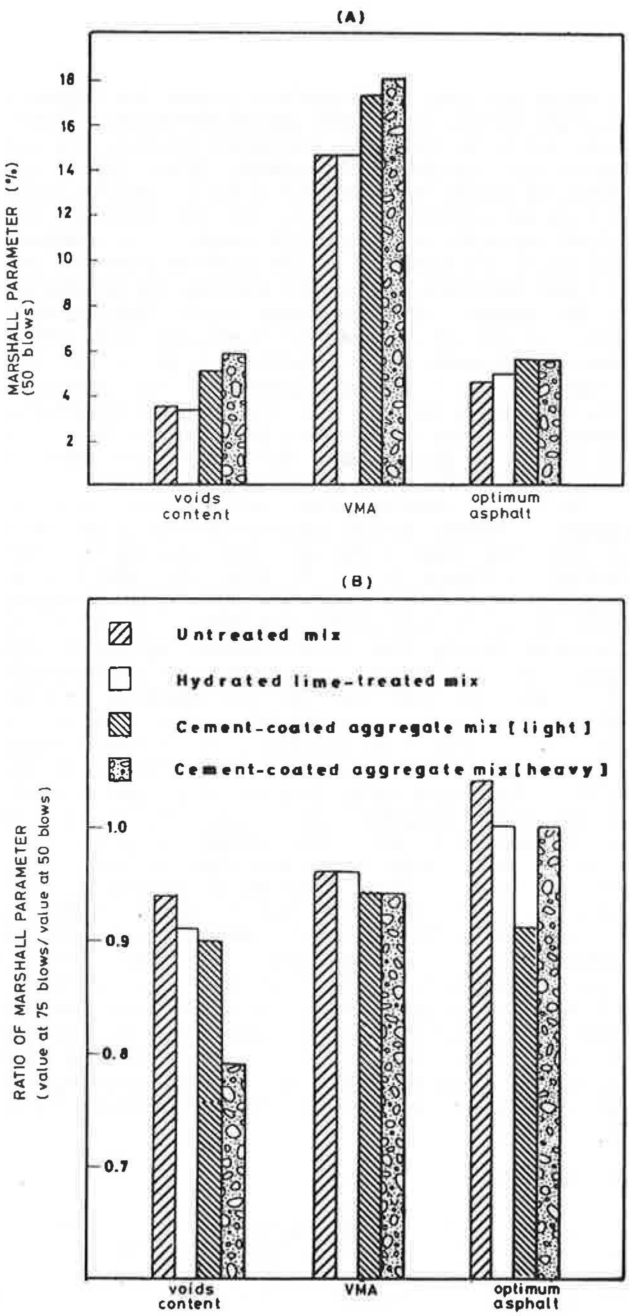
Note: 32 specimens were tested for each mix in rows 4, 5, 7, and 8; other mixes (rows 1, 2, 3, and 6) had 16 specimens each.

[a]Compaction is according to AASHTO T245 with 100 blows per side.

Table 4. Results of compactibility tests.

Type and Degree of Treatment	Optimum Asphalt (%)	Void Content (%)	Bulk Specific Gravity (g/cm^3)	VMA Value	Voids Filled with Bitumen (%)
Untreated mix					
50 blows	4.6	3.4	2.338	14.6	73
75 blows	4.8	3.2	2.351	14.0	79
Mix with hydrated lime, 1 percent					
50 blows	4.9	3.3	2.343	14.6	78
75 blows	4.9	3.0	2.358	14.0	81
Mix with cement-coated aggregate					
Light coat					
50 blows	5.5	5.1	2.290	17.2	72.5
75 blows	5.0	4.6	2.306	16.2	70
Heavy coat					
50 blows	5.5	5.8	2.27	17.9	68
75 blows	5.5	4.6	2.30	16.9	73

Figure 3. Compaction characteristics of asphaltic mixes under two different treatments.



Dynamic Response

An electrohydraulic testing machine was used to determine the dynamic modulus of compacted specimens of two mix types--hydrated lime-treated mix and cement-coated aggregate mix with light treatment. The specimens, which were 101.6 mm diameter and 203.2 mm high, were prepared according to ASTM D3496, capped with sulfur mortar according to ASTM C617, and tested at three frequencies (1, 4, and 16 Hz) and three levels of temperature (5, 25, and 45°C) according to ASTM D3497.

RESULTS AND DISCUSSION

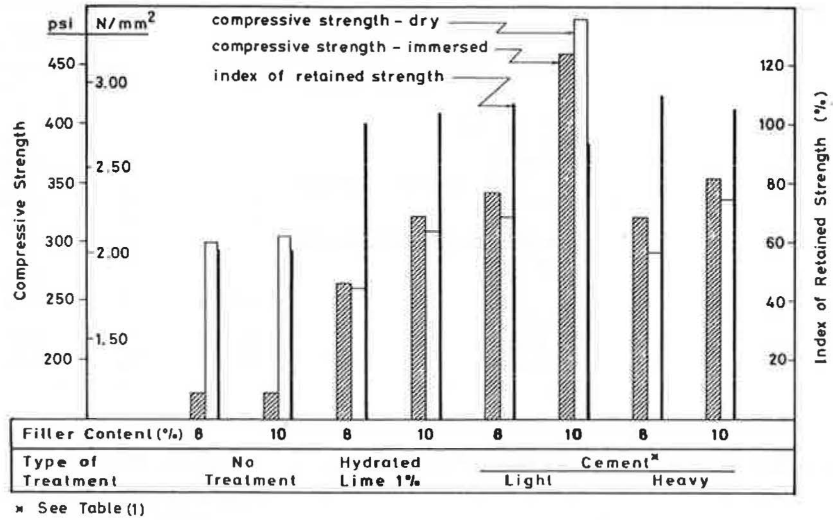
From the results of Marshall tests presented in Table 3, it can be seen that the untreated mix has the lowest stability in spite of its relatively high density (row 1). The addition of 1 percent by aggregate weight of hydrated lime (row 2) did not change the void content or density significantly, but it did increase stability by 9 percent. This increase in stability is believed to be due partly to the fineness of the hydrated lime compared with the limestone dust (specific surfaces of 750 and 260 m^2/kg, respectively), which produced a binder of higher viscosity.

Rows 3, 4, and 5 of Table 3 show that both voids and stability of the cement-treated mixes increase with the degree of cement coating. Specimens made with increasing levels of cement coating are respectively 10, 35, and 58 percent higher in voids and 4, 9, and 24 percent higher in stability than specimens made with untreated aggregates. The higher void content obviously indicates a reduction in compactibility of these mixes and is expected consequently to result in lower stabilities. However, it seems that the gain in mix stability due to enhancement of aggregate texture (by precoating with cement) is more than the loss due to lower density and higher voids of the resulting less-compactible mix.

When the three cement-treated mixes are prepared and tested at approximately equal void content (rows 6, 7, 8), the effect of the degree of cement treatment becomes more evident. In this case, the stability values of the medium treatment and the heavy treatment compared with that of the light treatment are respectively 21 and 35 percent higher. One advantage of using cement-coated aggregate mixes in relation to a hot climate becomes apparent, namely, their higher stability values obtained at comparatively higher void content. The result is a reduction of the potential for bleeding usually developed when mixes with already low void content are post-compacted under heavy traffic.

The compaction characteristics of the mixes under two levels of Marshall compactive efforts are presented in Table 4 and Figure 3. It is seen in Fig-

Figure 4. Resistance of differently treated asphaltic mixes to water action.



ure 3A that by applying the same effort for all mixes at their respective optimum asphalt contents, those made with cement-coated aggregates resulted in about 25 percent higher VMA values compared with that of the untreated case. Since the same gradation is used, the higher VMA values are indicative of the difficulty with which these mixes are compacted. Under a kneading type of compaction, this increase in VMA would probably be smaller due to the relative freedom of movement of the particles during the process of densification. The higher VMA values and optimum asphalt content can be referred to the increase in roughness of particle surface texture (2,9) after having been treated with cement.

In the extremely hot climate of Kuwait, where pavement surface temperatures during summer can exceed 70°C, asphaltic mixes should preferably have void contents near the upper permissible limit as a safety factor against potential fatting-up or bleeding. Void contents in this range are especially suitable in such an environment due to the scarcity of rainfall. The cement coating of aggregates appears to allow densely graded mixes of higher stability values to be used without the risk of closing the voids to an undesirably low level.

Increasing the compactive effort to 75 blows has no significant effect on the optimum asphalt content of different mixes (Table 4). Figure 3B, however, shows that due to their higher initial VMA, mixes with cement-coated aggregates compressed slightly more during the additional 25 blows than did conventional mixes (4 percent versus 6-10 percent reduction in VMA values for conventional and cement-treated mixes, respectively). This extra consolidation due to a higher level of compaction may be regarded as a rough simulation of the postcompaction to which an asphalt layer would be subjected under traffic.

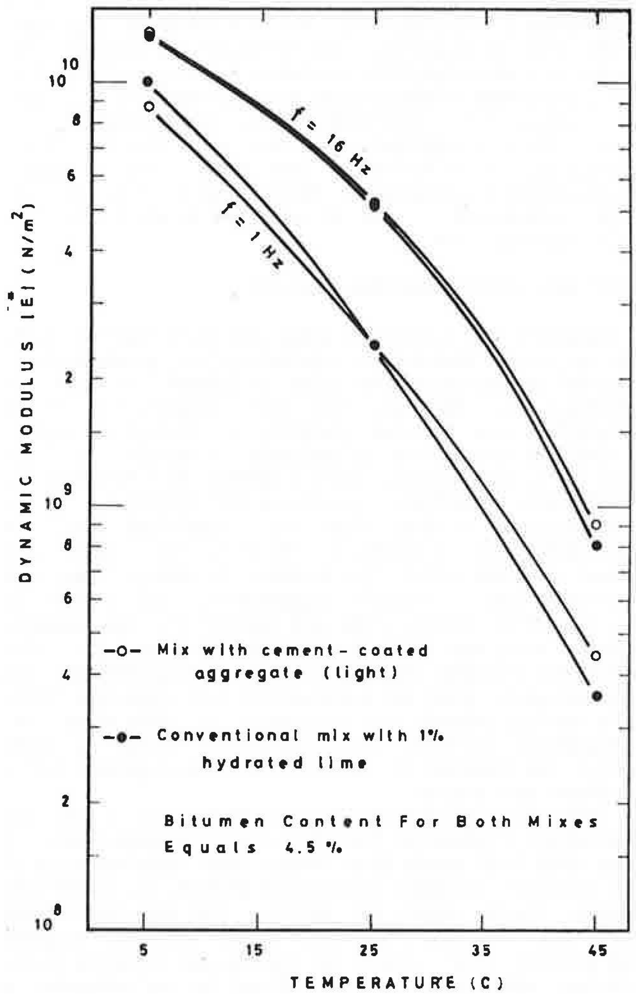
The effect of water immersion is shown in Figure 4. Although untreated specimens lost about half their compressive strength after immersion, specimens that had 1 percent hydrated lime and those treated with cement appeared completely resistant to water. The large drop in strength of untreated specimens occurs in spite of their fines content of 8 and 10 percent (mostly limestone dust), which ought to improve the mechanical component of adhesion and thus the resistance to stripping by increasing the viscosity of the original binder in the mix (2). However, unlike active fillers such as hydrated lime, limestone dust is inert and insoluble in water and does not therefore change the physicochemical mechanism at the aggregate-bitumen interface, which is known to influence greatly the adhesion and stripping of asphalt films (10). The change of filler content from 8 to 10 percent seems to have no significant effect on the index of retained strength in almost all cases. The compressive strength, however, in the case of both dry and immersed specimens is seen to increase by an average of 20 percent for specimens with hydrated-lime treatment and 13 percent for specimens with heavy-cement treatment. The maximum response to the change in filler content appears to be associated with the specimens that had light cement treatment. Increases of the compressive strength in this case are 52 and 34 percent for the dry and the immersed conditions, respectively.

The dynamic-modulus test results are shown in Figure 5. Values at the intermediate frequency of 4 Hz show the same trend but for clarity are not plotted in Figure 5. It is seen that the dynamic responses of the two mixes at the higher frequency level of 16 Hz are almost the same. At the lower frequency level, the cement-coated aggregate mix shows some improvement in temperature susceptibility. This is indicated by the slightly flatter stiffness-temperature relationship over that of the conventional mix. In addition, the cement-treated mix shows higher values of stiffness modulus at the higher temperature range (above 25°C), particularly at the lower frequency of 1 Hz. This could be interpreted as having better dynamic response as a pavement layer under heavy and slow traffic during the hot season. This increase in stiffness, however, is not of the order that permits a reduction in the design thickness of cement-treated asphalt layers (i.e., as a compensation for their improved load spreadability). Calculation of stress distribution, for instance, shows that the corresponding reduction in the vertical compressive stress on the subgrade due to the increase in stiffness at 45°C (Figure 5) is of the order of 7 percent only (assuming a two-layer pavement system with a modular ratio E1/E2 of 10).

CONCLUSIONS

1. The precoating of aggregates with 6.3 and 8.1 percent of portland cement (medium and heavy treatments) has the effect of increasing the Marshall stability of the resulting asphalt mixtures by 9 and

Figure 5. Effect of cement treatment on dynamic modulus of asphalt concrete.



24 percent, respectively. This was associated with an increase in the compacted voids.

2. When compared on the basis of approximately equal compacted voids, asphalt mixes with the medium and heavy cement treatments proved respectively 21 and 35 percent higher in stability than mixes with light cement treatment (4.9 percent cement).

3. The index of retained strength (immersion-compression ratio) increased from less than 60 percent for untreated mixes to almost 100 percent for mixes made with cement-coated aggregates at any of the coating levels investigated.

4. The use of cement-coated aggregates improved temperature susceptibility of mix stiffness in the low-frequency range of 1-4 Hz.

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Abridgment

Factors Affecting Unconfined Compressive Strength of Lime-Bituminous-Emulsion-Treated Clay

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A one-half 2^7 fractional factorial experiment design was used to evaluate the effect of soil type, lime content, molding moisture content, modification curing time, bituminous emulsion type, bituminous emulsion content, and curing temperature on the unconfined compressive strength of compacted specimens after a four-week postcompaction curing period. Analysis-of-variance techniques were used to determine the significant main effects, two-factor interactions, and three-factor interactions at alpha levels of 1 and 5 percent. In general, for the range of variables used in this research, the un-