

# Effects of Ambient Temperature and Thermal Cycling on the Creep of Bituminous Pavement Materials

R. J. SALTER AND M. Y. O. AL-SHAKARCHI

This paper discusses the effects of ambient temperature and thermal cycling on the creep of bituminous pavement materials, based on the results of laboratory testing. Two types of aggregate, rounded and crushed, and two grades of bitumen, 49 and 86 pen, were used to prepare laboratory samples that were subjected to uniaxial creep testing. The effect of ambient temperature changes on the performance of materials was investigated by thermal cycling and the effects on creep and mix stiffness reported. In summary, it was found that crushed gritstone aggregate showed creep-resisting properties superior to those of round gravel aggregates. Furthermore, the addition of ethylene vinyl acetate copolymer to the mixes studied resulted in considerable reduction in creep, which were particularly marked at higher ambient temperatures.

Climatic considerations are of major importance in the design, construction, and maintenance of bituminous pavements. High temperatures and temperature change in the bituminous layers play a significant role in the overall life of a pavement and in maintenance requirements. Creep within the pavement layers has an obvious influence on pavement stiffness and consequences for the development of rutting. Additionally, climatic changes can result in a loss of cohesion between aggregate particles, and the pavement designer has an interest in increasing the resistance force of mixture bonds by developments in binders, chemical additives, and aggregate grading and type.

The research described in this report addressed these problems by considering the following aspects of the behavior of bituminous materials:

1. The effects of high ambient temperatures (20°C, 40°C, and 50°C) and bitumen grade on the deformation behavior of different bituminous mixes, using the creep test as a test method;
2. The influence of aggregate type on mix stability;
3. The effect of ethylene vinyl acetate (EVA) binder modifiers on mix performance; and
4. The effect of thermal cycling on bituminous mixes, using the creep and Marshall tests.

## MATERIALS

Two types of aggregate were used in the experimental investigation: a crushed gravel and a crushed gritstone. These two types of material were selected as being representative of the

range of aggregate types used in pavement construction in Great Britain. Aggregate grading of the design mix used in all the experimental work is given in Table 1 and complied with specification limits outlined in ASTM D3515.

Two grades of penetration were used in the experimental work, a 40/60 penetration and an 80/120 penetration supplied by Croda Hydrocarbons. In some of the experimental mixes an ethylene vinyl acetate modified binder with a 5:95 by mass polymer to 80/120 penetration bitumen was used. Blending was carried out in a low shear mixer for approximately 2 hr. The properties of these binders are given in Table 2. The

TABLE 1 AGGREGATE GRADING FOR ALL MIXES

sieve size	% passing
1 in	100
$\frac{3}{4}$ in	98
$\frac{1}{2}$ in	87
$\frac{3}{8}$ in	78
No 4	60
No 8	42
No 50	16
No 200	6

TABLE 2 BINDER PROPERTIES

bitumen type	property	observed value
80/120	specific gravity	1.03
	softening point (R & B)	42°C
	penetration	86
	penetration index	-2.2
40/60	specific gravity	1.03
	softening point	48.5°C
	penetration	49
	penetration index	-1.6
80/120 + 5% EVA	specific gravity	1.02
	softening point	63.6°C
	penetration	44
	penetration index	+1.4

EVA copolymer contained 18 percent vinyl acetate, a mixture found particularly effective in previous work in Great Britain.

Optimum mix design was determined using the Marshall criteria. The optimum binder content, air voids, and densities for the mixes considered in the study are given in Table 3.

### CREEP TEST SPECIMENS

Compaction of bituminous materials has a considerable effect on the subsequent performance of in-service pavements as well as on the behavior of laboratory specimens.

Laboratory specimens used for the investigation into creep characteristics were prepared using a compacting procedure similar to that employed with the California Kneading Com-

pactor. It was anticipated that this procedure would result in uniform density throughout the specimens and an aggregate orientation similar to that achieved in the field by rolling operations. Compacted specimens were prism-shaped with the following dimensions: 200 mm by 100 mm by 100 mm.

### UNIAXIAL CREEP TESTS

The uniaxial creep apparatus has become widely used as a simple method for assessing the resistance to deformation of bituminous materials. At the international colloquium on plastic deformability of bituminous mixes held at Zurich in 1977, creep testing conditions were standardized at an axial stress of 0.1 MN/sq m (14.5 psi) for 60 min at a temperature of 40°C.

In the research work reported here, the following variables were included in the design of the experiment; temperature, vertical stress, binder type, aggregate type, and thermal conditioning. The experimental arrangement for creep testing is given in Table 4. Complete details of the creep testing procedure are given elsewhere (1).

TABLE 3 MIX PROPERTIES

mix	optimum binder content %	average voids content %	average mix density gm/ml
gravel aggregate 49 pen binder	5.7	2.9	2.36
gravel aggregate 86 pen binder	5.7	2.1	2.39
gritstone aggregate 49 pen binder	5.5	3.4	2.43
gritstone aggregate 86 pen binder	5.7	3.3	2.44
gritstone aggregate 86 pen binder + EVA	5.7	3.2	2.43

### CREEP TEST RESULTS

Creep testing was carried out at temperatures of 20°C, 40°C, and 50°C. It was found that gravel aggregate mixes with 86-pen binder, tested at a stress of 0.1 MN/sq m, failed after 10 min of load application. Lowering the test temperature prevented failure before the end of the 60-min test period; nevertheless, strains were very much greater than those experienced with the other mixes tested. After 10 min of load application, the vertical strain at 40°C was approximately three times higher and, at 50°C, more than four times higher than strains expe-

TABLE 4 EXPERIMENTAL ARRANGEMENT FOR CREEP TESTING

gritstone aggregate					gravel aggregate				
stress	bitumen	test temperature		number of specimens	stress	bitumen	test temperature		number of specimens
		C°	F°				C°	F°	
0.2 MN/m <sup>2</sup> (29.0 psi)	86 pen	20	68	4	0.2 MN/m <sup>2</sup> (29.0 psi)	86 pen	20	68	4
		40	104	4			40	104	4
		50	122	4			50	122	4
	49 pen	20	68	4		49 pen	20	68	4
		40	104	4			40	104	4
		50	122	4			50	122	4
0.1 MN/m <sup>2</sup> (14.5 psi)	86 pen	20	68	4	0.1 MN/m <sup>2</sup> (14.5 psi)	86 pen	40	68	4
		40	104	4			40	103	4
		50	122	4			50	122	4
	49 pen	20	68	4		49 pen	20	68	4
		40	104	4			40	104	4
		50	122	4			50	122	4
	EVA + 86 pen at ratio of 5/95	20	68	4					
		40	104	4					
		50	122	4					

rienced at 20°C. Details of the creep test procedure are given elsewhere (1).

Stress testing at 0.2 MN/sq m indicated, as would be expected, even greater axial strain. The 86 pen binder gritstone mixes and 49 and 86 pen binder gravel mixes all failed before the completion of testing at temperatures of 40°C and 50°C.

The greatest strain occurred at all temperatures and both stress levels with the gravel aggregate mix with 86 pen binder, and the least strain occurred with the gritstone aggregate with 49 pen binder.

#### EFFECT OF EVA COPOLYMER ON CREEP

The effect of adding 5 percent by mass of ethylene vinyl acetate copolymer to the mix on vertical and transverse strains was investigated with the creep test, using an axial stress of 0.1 MN/sq m. Three different test temperatures were used: 20°C, 40°C, and 50°C.

It was noted that the addition of EVA considerably reduced the creep of mixtures, the effect being particularly marked at higher temperatures. Figure 1 shows this effect on creep measurements at 20°C, 40°C, and 50°C for mixes with an 86 pen binder, with and without the addition of ethylene vinyl acetate.

In addition to the stiffening effect of EVA on existing bituminous mixtures, the use of the copolymer allows improved creep performance to be obtained with mixes containing binders of increased penetration. This is a factor of considerable significance in situations where climatic conditions limit the time available for compaction before the temperature of the material on the pavement falls below the minimum rolling temperature, when air voids may remain at unsatisfactory levels. Figure 2 shows a comparison between the vertical strain observed in gritstone mixes containing 49 pen binder and similar mixes containing 86 pen binder and EVA. A considerable reduction in creep for the specimens containing the modified binder can readily be observed.

#### EFFECT OF EVA COPOLYMER ON STIFFNESS

The results of the creep tests can be expressed in terms of mix stiffness related to loading time. Stiffness values for gritstone mixes containing 86 pen binder, subjected to an axial stress of 0.1 MN/sq m at test temperatures of 20°C, 40°C, and 50°C, are shown in Figure 3. Considerable increases in observed stiffness values can be seen for specimens containing copolymer at all test temperatures and loading times.

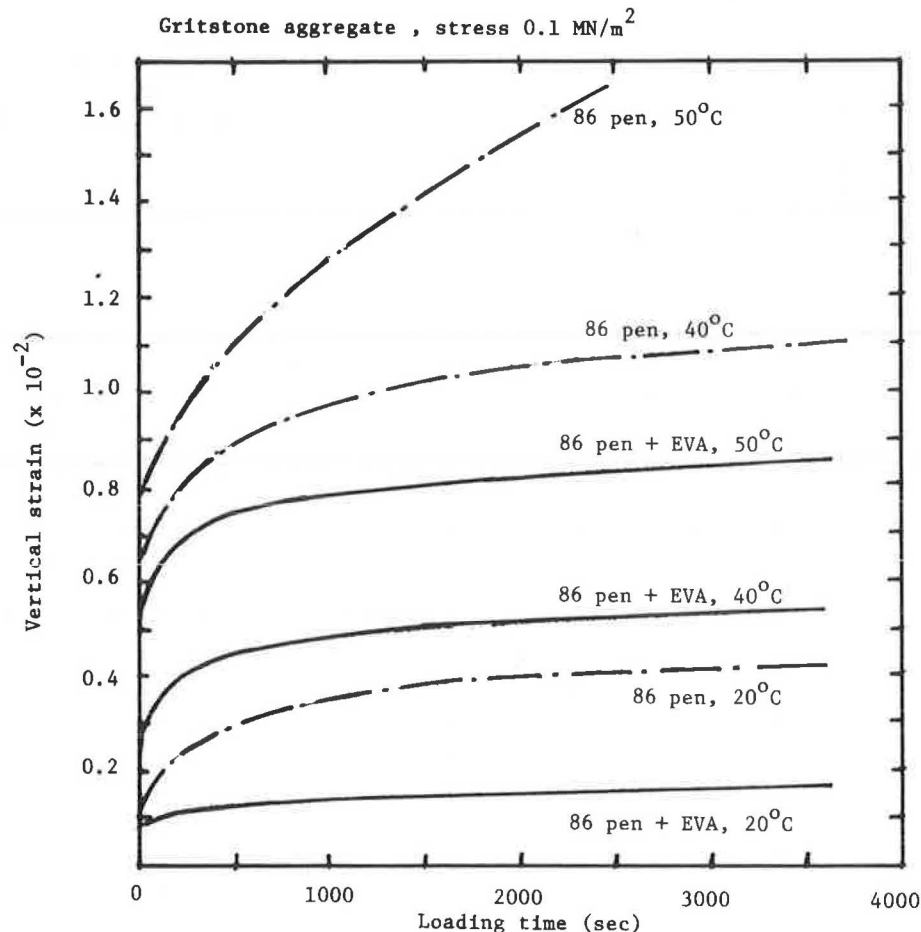
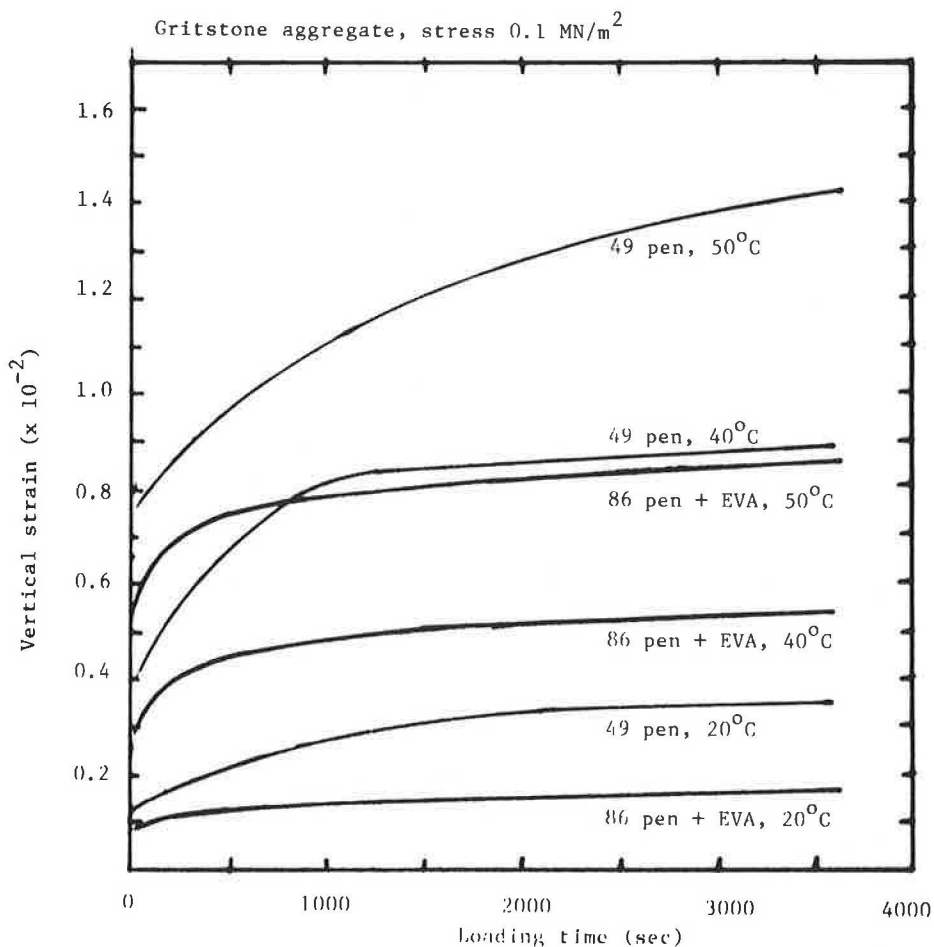
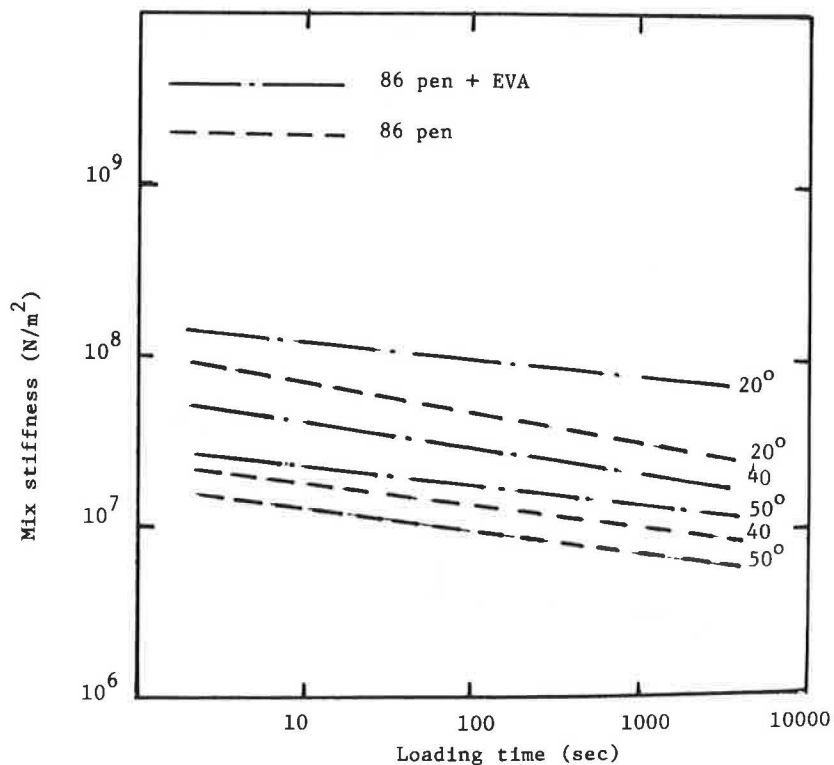


FIGURE 1 Effects of temperature and polymer additive on creep for gritstone aggregate and 86 pen binder.



**FIGURE 2** Effect of temperature, bitumen penetration, and polymer additive on creep for gritstone aggregate.



**FIGURE 3** Effect of temperature, loading time, and polymer additive on mix stiffness for gritstone aggregate.

### THERMAL CONDITIONING

The effects of thermal conditioning were investigated by subjecting specimens to between 1 and 20 cycles of temperature variation, between 1°C and 55°C. Specimens were placed in the heating oven at an air and specimen temperature of 25°C; then the oven temperature was raised, reaching 55°C in approximately 110 min, and was maintained at the level for 40 min. Specimens were then cooled in air for a period of 90 min until they reached 25°C. Specimens were further cooled in water to a temperature of 1°C for a period of 150 min; they were then removed from the water and allowed to reach 25°C in 90 min. The whole temperature conditioning cycle occupied 8 hr.

### EFFECT OF THERMAL CONDITIONING

Thermal conditioning was applied to two types of specimens: prism and Marshall specimens. The first specimen type was tested using creep testing and the second type, according to the Marshall test procedure. Thermal damage was measured through changes in creep properties and in stiffness related to the extent of thermal conditioning.

Creep testing was performed on specimens that had been subjected to 0, 1, 5, 10, and 20 cycles of thermal conditioning. As previously observed, mixes with gritstone aggregate and 86 pen binder had higher creep values than a similar mix incorporating EVA copolymer at 0 conditioning cycles. It was also observed that, for any specific mix, the creep increased

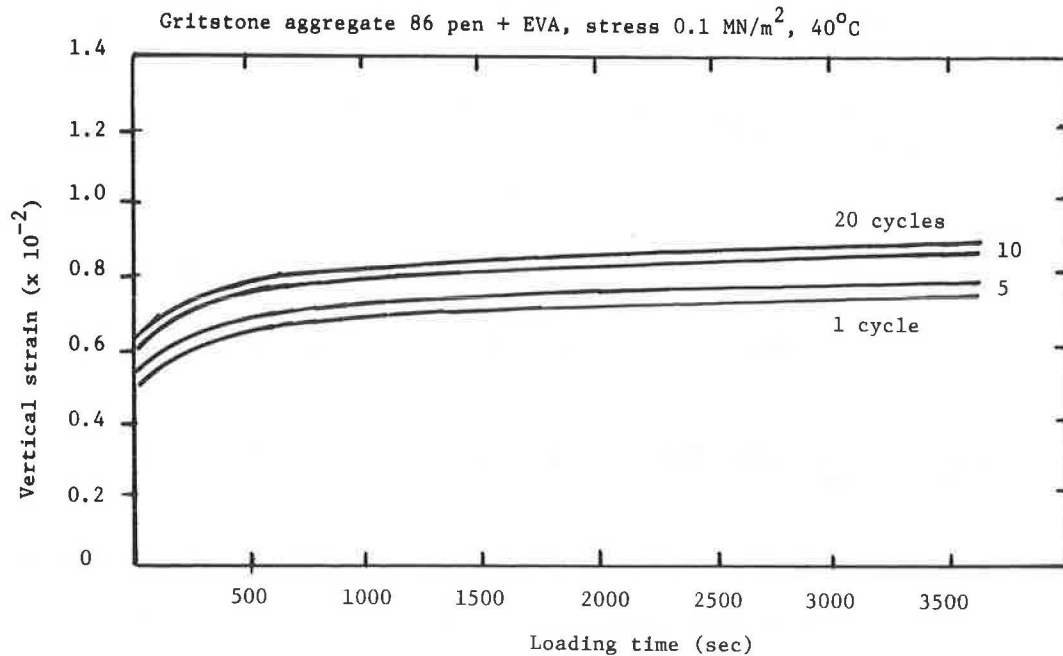


FIGURE 4 Effect of thermal cycling on creep, gritstone aggregate, 86 pen bitumen plus EVA.

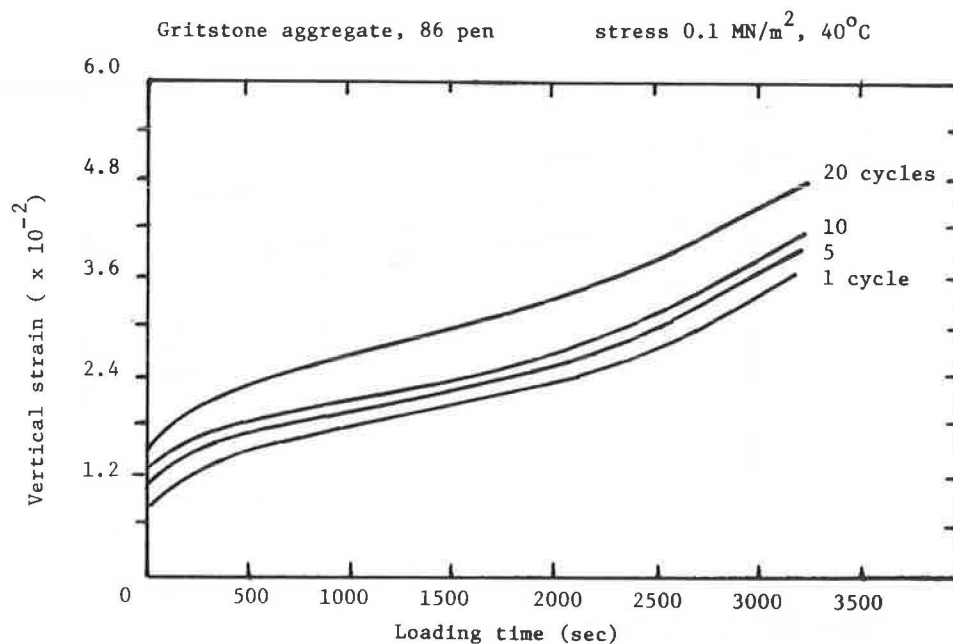


FIGURE 5 Effect of thermal cycling on creep, gritstone aggregate, 86 pen bitumen.

TABLE 5 EFFECT OF MIX TYPE AND THERMAL EXPOSURE ON VERTICAL STRAIN

mix	loading time (min)	Vertical strain at different cycles			
		1	5	10	20
gritstone 86 pen	* 54	0.0368	0.0392	0.0417	0.04750
gritstone 86 pen 5% EVA	60	0.00745	0.00772	0.00853	0.00868

with the number of thermal cycles to which the samples had been subjected. At any given number of thermal conditioning cycles, the samples containing EVA copolymer had lower creep values than did similar mixes without the added copolymer. The observed results are illustrated in Figures 4 and 5 and in Table 5.

The transverse strain of mixes subjected to differing numbers of thermal conditioning cycles was also measured during creep testing. The effects of the inclusion of EVA copolymer in the binder for a 60-min loading time are given in Table 6.

The effects on mix stiffness of thermal conditioning were determined from creep testing observations and are given in Table 7 for loading times of 2, 26, and 60 sec. The greatly increased mix stiffness of specimens containing EVA copolymer can clearly be seen. There is also a decrease in mix stiffness with exposure to thermal cycling. This stiffness decrease averages 40 percent for gritstone aggregate specimens and 86 pen binder, but amounts to an average of only 16 percent when EVA copolymer is incorporated in the mix.

The effects of exposure to thermal conditioning were examined by the Marshall test procedure, and details are given in Table 8. For the two mixes tested, gritstone aggregate and 86 pen binder with and without the addition of EVA copolymer, it can be seen that stability decreased and flow values increased with an increase in the number of thermal cycles.

With the limited number of thermal cycles applied to the test specimens, it was observed that the physical properties used in the Marshall test procedure to evaluate deteriorated mixes declined (with typical reductions in stability of 20 percent), increased the flow to 12 percent, and showed reductions of 30 percent in the Marshall Quotient.

## CONCLUSIONS

The research program (1) outlined in this paper indicated the superior creep-resisting properties of crushed gritstone aggregate compared with rounded gravel aggregates; it also indicated a decrease in creep with higher penetration binders and lower ambient-temperature testing conditions. The addition to the mix of ethylene vinyl acetate copolymer resulted in a considerable reduction in creep under the test conditions, and this reduction was particularly marked at higher ambient temperatures. Mix stiffness was also increased considerably by the addition of a copolymer. An attempt to assess the effect of severe temperature changes on the performance of bituminous pavement material was made using thermal cycling. The experimental results, using the Marshall test procedure and also creep testing, indicated a reduction in thermal cycling damage for specimens that contain copolymer when measured by vertical and transverse strains, mix stiffnesses, and Marshall test results.

TABLE 6 EFFECT OF MIX TYPE AND THERMAL EXPOSURE ON TRANSVERSE STRAIN

mix	transverse strain at different cycles			
	1	5	10	20
gritstone 86 pen	0.00409	0.00428	0.00454	0.00522
gritstone 86 pen 5% EVA	0.000572	0.000717	0.000887	0.00102

TABLE 7 EFFECT OF MIX TYPE AND THERMAL EXPOSURE ON MIX STIFFNESS

mix	loading time (sec)	stiffness at different cycles ( $\times 10^6$ N/m <sup>2</sup> )			
		1	5	10	20
gritstone 86 pen	2	15.18	12.15	10.38	9.74
	26	11.03	8.46	7.70	6.27
	60	9.79	7.65	7.02	5.67
gritstone 86 pen 5% EVA	2	25.58	24.81	23.31	22.57
	26	20.00	19.34	17.04	16.56
	60	18.62	17.95	15.70	15.24

TABLE 8 EFFECT OF THERMAL CONDITIONING ON MARSHALL VALUES

mix	cycles	stability kN	flow mm	Marshall Quotient
gritstone 86 pen	0	11.89	4.42	2.69
	1	10.94	4.55	2.41
	5	9.76	4.62	2.11
	10	9.65	4.78	2.02
	20	9.40	4.92	1.91
gritstone 86 pen 5% EVA	0	12.94	4.15	3.12
	1	11.62	4.20	2.77
	5	11.34	4.37	2.59
	10	11.00	4.57	2.41
	20	10.58	4.71	2.25

## REFERENCE

1. M. Y. O. Al-Shakarchi. *Effects of Ambient Temperatures and Thermal-Cycle Conditioning on the Deformation of Bituminous Pavement Material*. Ph.D thesis. University of Bradford, England, 1988.

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