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FATIGUE RESISTANCE OF DENSE BITUMEN MACADAM: THE EFFECT OF MIXTURE VARIABLES AND TEMPERATURES

by

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ABSTRACT

Better compaction achieved at little or no extra cost has been shown to improve the performance of dense bitumen macadam. In the present work economically attractive coated macadams of low binder content are shown to have a reduced fatigue resistance but this may be offset by extra compaction.

Samples of material containing 40mm maximum size aggregate and 100 pen bitumen were cut from experimental pavements laid in a pilot-scale test facility and were loaded in direct sinusoidal tension and compression until fracture.

Although fatigue life is shown to be greater at higher test temperatures for a particular strain level this effect is far outweighed by the associated reduction in stiffness. The effect of the type of aggregate in the mixture on its fatigue resistance is small compared with that of the other factors studied. An equation relating laboratory fatigue life, binder content, compaction level and test temperature was developed using a standard multiple regression technique.

Other aspects of the role of bituminous materials in determining pavement performance require evaluation before roadbases of low binder content can be introduced with confidence. A wider programme of research is therefore being carried out to study other properties related to structural performance.

1. INTRODUCTION

In the United Kingdom the use of dense coated macadams as roadbase and base-course material has become widespread in recent years, both in new construction and in road reconstruction. This continuously graded material is manufactured to a composition specification[1] for both grading and binder content and there are no compaction requirements other than the specification of the type of roller and rolling temperature.

The performance of dense coated macadams has been considered to be generally satisfactory, their greater cost per unit thickness in relation to that of crushed stone and cement-bound materials being offset by their superior performance. However previous work[2] has shown that there is considerable scope in the United Kingdom for improving the compaction and, consequently, the performance of these materials at little or no extra cost by modifying the rolling procedures. It is now commonly believed that the current composition specification could also be improved.

A joint programme of research was therefore initiated by the Asphalt and Coated Macadam Association, the British Tar Industry Association, the Refined Bitumen Association and the Transport and Road Research Laboratory, to investigate the possibility of improving the effectiveness of roadbase and basecourse macadams in relation to their cost with the particular aim of developing coated macadams of lower binder content compacted to the maximum extent. Research effort is therefore now being devoted to pilot-scale and laboratory studies to determine the compaction characteristics and performance of coated macadams of low binder content.

An effective roadbase material must have satisfactory stiffness over the range of road temperature in order to spread the traffic stresses efficiently. It must also have adequate resistance to internal deformation and to fatigue cracking. This Report describes that part of the programme of work which involves the measurement under controlled laboratory conditions of the resistance to fatigue cracking of dense bitumen macadams containing a range of binder content and at different levels of compaction. There is no evidence in the UK of failure by fatigue cracking of bituminous roadbase materials in current use and an authoritative correlation between laboratory fatigue behaviour and the performance of full-scale road pavements is not yet available. However, laboratory fatigue results are of value when used for comparative purposes. Thus, they can be used to study the effects of such factors as temperature on fatigue resistance in order to indicate the road conditions when fatigue problems are most likely to occur, and to compare the fatigue resistance of materials of broadly the same composition.

2. TEST PROCEDURES AND CONDITIONS

The effect of mixture variables on fatigue strength of dense bitumen macadams currently specified in the UK has been reported by Cooper and Pell[3]. The programme of testing described here was planned to investigate the effect on fatigue resistance of dense bitumen macadam of:

(a) reducing binder content below the current minimum specified in the UK for roadbase materials ie extending the range of binder content studied by Cooper and Pell.

(b) varying compactive effort; this has not previously been studied for roadbase materials complying with the current UK specification.

(c) varying the test temperature; the published evidence on the effect of this factor is contradictory.

(d) the type of aggregate; a rounded gravel and two crushed-rock aggregates were included in the study to check whether the relationships established in (a), (b) and (c) are sensitive to this factor.

2.1 *Preparation of laboratory test specimens*

Relationships between material composition, compaction and structural performance are being obtained from studies made on experimental pavements constructed in pilot-scale trials. These trials are carried out in a pilot-scale test facility on a foundation of realistic stiffness, comprising a 100 mm thick crushed-granite sub-base on a subgrade of heavy clay. Testing of material prepared by small-scale laboratory compaction is not recommended because the behaviour of this material is likely to be different to that compacted using full-scale equipment.

Dense bitumen macadam containing 40mm maximum-size aggregate to the present grading specification[1] was mixed with 100 pen bitumen in the Laboratory's experimental bituminous mixing plant. The aggregate types studied were a crushed granite, a crushed limestone, and uncrushed gravel. Each trial material was laid, using a Blaw Knox PF 90 paver, to an uncompacted depth of about 175 mm over an area 30 m x 2.8 m and the laid material divided into three areas which were subjected to 3, 9 and 25 passes respectively of an 8.5 tonne tandem deadweight roller. The range of roller passes was extended to include the 40-pass level for the granite material containing 2.7 per cent bitumen and for all limestone materials. In each trial, samples were analysed for aggregate grading, bitumen content and properties of the recovered bitumen. Table 1 summarizes the type and grading of aggregate used and properties of the recovered binder. The bitumen content of each material is given in Table 2.

Slabs, one metre square, were then removed from each trial area of the pilot-scale pavement and, from these, test prisms 75 mm square and 225 mm long were cut using a diamond-tipped saw, so that the long axis of each prism was parallel to the direction of rolling. A jig was used to ensure dimensional accuracy within ±1.5 mm of nominal dimensions.

Each prismatic specimen was weighed in air and water to obtain its density, the specimens having been coated with wax before weighing to prevent water absorption. Results of density measurement and composition analyses were used to calcuate the void content and voids in the mineral aggregate (VMA) of each specimen; mean values for test specimens taken from each area of the pilot-scale pavement are shown in Table 2.

It was planned to test material containing granite aggregate mixed with 2 per cent bitumen but when laid this did not have sufficient integrity for specimens to be cut for testing; this material would certainly give unsatisfactory performance on the road.

2.2 *Method of test*

Steel loading-plates were bonded to the square ends of each specimen with an epoxy-resin using a specially prepared jig to ensure accurate alignment.

Each prismatic specimen was loaded in direct sinusoidal tension and compression in a servo-controlled electro-hydraulic testing machine. The test equipment is illustrated in Figure 1 and Plate 1. Each specimen was connected rigidly at its end-plates between the reaction frame of the testing machine and the load cell on the piston rod of the hydraulic actuator. The specimen and the upper part of the reaction frame were enclosed in a cabinet which maintained the temperature constant to within ±0.5°C. The loading was controlled by electrical signals from a function generator and the load amplitude was kept constant throughout a particular test using feedback from the load cell.

In order to avoid creep in the test specimen during a test because of small low-frequency deviations in the applied load, a control circuit was used which applied continually a correction to the mean load.

Linear variable displacement transducers (LVDT's) were used to measure the overall dynamic deflection between the end-plates throughout each test, their output being recorded on light-sensitive paper using an oscillograph. Load and displacement traces were displayed on a cathode-ray oscilloscope. The number of tests completed to characterise the fatigue performance of each material at a given test condition was generally in the range 8 to 22 and in each test a note was made of the number of load cycles at fracture.

2.3 *Test conditions*

The frequency of loading of each specimen was 25 Hz. The dynamic stress was chosen to enable the fatigue characteristics of the materials tested to be compared over similar ranges of fatigue lives and was of the order of that at the bottom of the bound layer of a flexible pavement, directly beneath a moving wheel load; this zone is generally considered the most susceptible to fatigue cracking[4]. The stress amplitudes were in the range 0.03 to 0.8 MN/m^2. The controlled-stress mode of testing was used because this is more applicable[5] in evaluating the dense coated macadams frequently used in the UK in the construction of thick roadbases and base-courses. This procedure also has the advantage that the failure point is well defined. The temperatures at which the testing was carried out are given in Table 2.

3. RESULTS OF FATIGUE TESTS

It is generally accepted[3,5] that in laboratory fatigue tests of a particular bituminous material at a given temperature, the prime factor controlling the onset of cracking is the maximum dynamic tensile strain in the specimen. The most logical characteristation of tensile strain for the purpose of analysis and design would be a mean level during all or the major part of the life of the specimen; however difficulties arise in defining a mean value which is satisfactory in all circumstances and, because the best correlation with fatigue life is obtained with tensile strain at the beginning of the test, this factor is used to describe fatigue behaviour. The laboratory fatigue performance of a particular mixture may be characterised by the relationship between the 'initial' tensile strain, ε, and the number of load cycles to failure, N, which is of the form:

$$N = K \left(\frac{1}{\varepsilon}\right)^n \qquad \text{............ (1)}$$

where K and n are constants for a particular material and test condition.

Regression analyses of the test data yielded values of K and n for each level of compaction, binder content, aggregate type and test temperature. The slope, n, appears to be independent of the factors studied and its mean value was found to be 4.2. The effect on fatigue resistance of varying the mixture composition and test temperature can therefore be deduced from the values of initial strain corresponding to a fatigue life of 10^4 load cycles, $\varepsilon(N = 10^4)$.

Table 3 shows that $\varepsilon(N = 10^4)$, and therefore the fatigue resistance, increases with increasing binder content; any effect of compactive effort or type of aggregate is small in comparison with that of binder content. The effect on the strain/life relationship of varying the binder content is shown more clearly in Figure 2 where the strain/life curves are plotted for maximum and minimum binder contents of granite, gravel and limestone materials, and also in Figure 3 where the initial strain for a given life, $\varepsilon(N = 10^4)$, and therefore the fatigue resistance of all material tested at 25°C, increases with increasing binder content. The type of aggregate has relatively little effect. The only anomalous result is that for the gravel material containing 7.7 per cent by volume of bitumen; the fatigue resistance of this material at 25°C appears to be the same as that for material containing 6.4 per cent by volume of bitumen. This anomaly is almost certainly because of experimental error; the material containing 7.7 per cent bitumen was tested at one compaction level only whereas the material containing 6.4 per cent bitumen was tested at three compaction levels.

The relationship between initial strain and fatigue life was also found to be dependent upon temperature; Figure 4 shows this for granite material containing 2.7 per cent bitumen. The effect of temperature on $\varepsilon(N = 10^4)$ for the five mixtures studied is given in Table 4 and, for each material, $\varepsilon(N = 10^4)$ increases with increasing temperature.

Comparing the fatigue resistance of a variety of materials solely on the basis of the laboratory-determined relationship between the initial dynamic strain and the number of load cycles to failure does not take into account the fact that, in the road, the critical strain at the bottom of the bound layers depends upon the stiffness of these layers. This can be illustrated by considering a simple pavement as a single elastic layer of thickness h and stiffness E_1 on a soil foundation of stiffness E_2. When E_1 is appreciably greater than E_2 the maximum tensile strain at the bottom of the roadbase is proportional to[6]:

$$\left(\frac{1}{h}\right)^{1.8} \cdot \left(\frac{1}{E_1}\right) \cdot \log\left(\frac{E_1}{E_2}\right) \qquad \ldots\ldots\ldots\ldots (2)$$

The tensile strain in the roadbase decreases with increasing pavement stiffness for all practical circumstances. The fatigue life, given by Equation (1), will therefore increase considerably as a consequence of a small increase in stiffness of the roadbase.

The dynamic stiffness of the test specimen at the start of each test was therefore calculated from the dynamic stress amplitude and the initial dynamic strain amplitude. Figure 5 shows that stiffness increases as void content decreases as a consequence of increasing either bitumen content or compactive effort.

4. DISCUSSION OF THE EFFECT OF MIXTURE VARIABLES AND OF TEST TEMPERATURE

4.1 *Binder content*

It is widely acknowledged that binder content is a primary factor affecting fatigue performance[3,7,8]; for conventional materials, the resistance to fatigue at a particular initial dynamic strain increases with increasing binder content, up to a certain limit. This has been shown, as a result of the fatigue tests described here, to hold for bitumen contents down to 2.4 per cent, considerably lower than the current minimum specified in the United Kingdom for dense bitumen macadam. In the present work a one per cent reduction in binder content, typically, reduces the laboratory fatigue life by about 70 per cent. Figure 3 shows that the effect of binder content predicted by Cooper and Pell[3] from a knowledge of binder volume and Ring and Ball Softening Point is in good agreement with the present data.

A reduction in binder content will also affect the void content of the material (Table 3) and consequently the stiffness (Figure 5). A one per cent reduction in binder content reduces the stiffness by about 20 per cent. The consequent increase in initial strain suggested by Equation (2) depends greatly on temperature; for temperatures in the range 10° to 35°C the increase in strain will be between 10 and 20 per cent and the corresponding reduction in life is between 30 and 50 per cent. The reduced stiffness of a material of low binder content will result in a substantially shorter fatigue life for a pavement which contains such a material, as compared to the life of a material containing a conventional bituminous mixture; this comparison relates to materials whose compacted state in terms of VMA are equal. This reduction in life is additional to the adverse effect on the strain/life relationship.

4.2 *Compaction*

From Table 3 it is evident that the effect of compactive effort on the strain/fatigue-life relationship is small compared with the effect of binder content. Typically, a decrease in VMA of 3 per cent reduces fatigue life at a given strain by about 25 per cent. Verstraeten[7] predicts an opposite effect to this, whereas Pell[3] and Kirk[8] have concluded that level of compaction does not directly affect the strain/fatigue-life relationship. In the road however any effect of compaction on the strain/life relationship is small in comparison with the influence of compaction on mixture stiffness and, consequently, on the tensile strain produced by a given load. Changes in the void content of the mixtures tested in the present work had a large effect on stiffness and were the result of changes in either compactive effort or binder content.

The results presented in Figure 3 demonstrate that a reduction of stiffness associated with the reduction of binder content, and consequently an increase in void content, may be compensated for if better compaction can be achieved; however the fatigue life is more sensitive to change in binder content than change in compaction because of the substantial additional effect of the binder content on the strain/life relationship (Figure 2). The effective decrease of fatigue resistance associated with a reduction of binder content depends on the extent of the improvement in compaction achieved and the decrease in binder content considered; calculations using Equations (1) and (2) at a temperature of 25^{o}C and frequency of loading of 25Hz indicate that a six per cent reduction in VMA is necessary to compensate for the lower fatigue resistance of roadbase macadam containing about 0.5 per cent less bitumen than the target value specified.

4.3 *Type of aggregate*

It can be inferred from the work of Kirk[8] and of Cooper and Pell[3] that the effect of aggregate type on the initial strain/fatigue-life relationship is small. Huang and Grisham[9] have also concluded that, for materials of a given void content and binder content, the aggregate shape has no effect on the resistance to fatigue.

Figures 2 and 3 show that material containing limestone aggregate exhibits a slightly higher fatigue resistance than the other materials at a particular strain level and binder content. On the other hand there was no significant difference between the initial-strain/fatigue-life relationships for gravel and granite. The differences in fatigue characteristics can possibly be accounted for by differences in binder properties rather than differences in type of aggregate; Table 1 shows that the binder properties of the limestone materials were different from those of the granite and gravel materials. However any effect of aggregate type on the strain/life relationship is small compared with the effect of binder volume.

The results presented in Figure 5 show no marked effect of aggregate shape on the relation between stiffness and void content but there is some evidence to suggest that the stiffness of gravel material is less sensitive to change of void content than that of granite material. Also, the limestone material generally appears slightly stiffer than the granite and gravel materials. More detailed measurements of complex modulus of these materials and viscosity of the binders are under way and the results should clarify to what extent the differences in stiffness are attributable to aggregate type.

4.4 *Test temperature*

There is contradictory evidence about the effect of test temperature upon fatigue resistance determined by controlled-stress laboratory tests. Several studies have shown[3,7,10] that a wide variation of test temperature has no effect on the relation between initial strain and the number of cycles to failure. Others[11,12,13] however, have demonstrated that, as temperature increases, the strain at a given life $\varepsilon(N)$ increases, ie there is a shift in the strain/life curve towards longer life.

Kirk[8] has concluded that, for a given life, the ratio of initial strain to percentage volume of binder, ε/VB, decreases with increasing temperature until a minimum value is reached; thereafter ε/VB increases with increasing temperature. Over the range of temperature covered in the present work, Kirk's results predict that for a given material $\varepsilon(N)$ increases with temperature and the present results are in broad agreement.

The contradictory evidence published about the effect of test temperature on the strain/fatigue-life relationship must be considered in relation to the fact that increasing the temperature of a mixture also reduces its stiffness. Over the temperature ranges relevant to the road situation, the effect of this loss of stiffness on laboratory fatigue resistance at a given stress level far outweighs the increase in $\varepsilon(N = 10^4)$.

5. MULTIPLE REGRESSION ANALYSIS OF FATIGUE RESULTS

The main objective of the present work was to investigate the effect on fatigue resistance of varying the per cent binder volume VB, test temperature T(^{o}K) and compaction in terms of VMA. Exact values of VMA and binder content could not be obtained when preparing specimens. Although this did not allow the systematic variation of the factors for a particular method of analysis, an equation derived using a standard multiple regression technique[14] described the relationship between the strain corresponding to a life of 10^4 cycles, $\varepsilon(N = 10^4)$, and the factors VB, T and VMA with reasonable accuracy as shown in Figure 6. This equation is

$$\varepsilon(N = 10^4) = 1.54.10^{-21}.(VB)^{.95}.(T)^{6.11}.(VMA)^{.754} \quad \dots\dots\dots\dots (3)$$

There is some evidence in Figure 6 that the relationship given in Equation (3) is sensitive to the type of material tested and a further term in the equation, reflecting some other property of the material, possibly of the binder, is required for greater accuracy of prediction. A similar analysis performed by Cooper and Pell[4] for a wider range of variables using the results of their rotating/bending fatigue test, has shown that binder softening point is also a significant material property influencing the strain/life relationship. However, every effort was made to reduce the variability of this property to a minimum for the present work and further complication of the equation is not justified for the results presented. The equation quantifies adequately the effects of three of the variables discussed in Section 4 on the laboratory fatigue resistance of 40mm nominal-size dense roadbase macadam containing 100 pen bitumen; fatigue resistance of materials of different aggregate grading or containing different binder types has not been studied and is not therefore characterized by Equation (3).

6. CONCLUSIONS

1. The initial-strain/fatigue-life relationship determined under controlled laboratory conditions for dense bitumen macadam roadbase materials containing less than the currently specified amount of binder is shown to conform

to that previously established for richer mixtures; material with less binder is considerably less resistant to fatigue cracking.

2. A change in compactive effort has a relatively small effect on the strain/fatigue-life relationship. This effect is more than compensated for by the corresponding change in stiffness.

3. Changes in void content as a result of changes in either compactive effort or binder content had a large influence on stiffness. The relatively poor performance to be expected of low-binder-content materials as indicated by laboratory fatigue testing can therefore be offset by increasing compaction; for example, at 25°C and 25 Hz a six per cent reduction in VMA is necessary to compensate for the lower fatigue resistance of roadbase macadam containing about 0.5 per cent less bitumen than the target value specified.

4. The limestone material had a slightly greater resistance to fatigue cracking than the materials containing either gravel or granite, but this need not necessarily have been a result of aggregate type; differences in binder properties between samples of the different materials are probably responsible. The effect of aggregate type on fatigue performance is small but has not been clearly established by the present work.

5. The present studies show that the test temperature influences the laboratory fatigue performance of bituminous mixtures tested under conditions of controlled stress. An increase in temperature increases the fatigue life corresponding to a particular value of dynamic strain in the mixture at the start of the fatigue test. This effect is, however, far outweighed by the associated reduction in stiffness when the temperature increases.

6. The relation

$$\varepsilon(N = 10^4) = 1.54 \,.\, 10^{-21} \,.\, (VB)^{.95} \,.\, (T)^{6.11} \,.\, (VMA)^{.754}$$

where $\varepsilon(N = 10^4)$ = initial strain corresponding to a laboratory fatigue life of 10^4 cycles

VB = binder volume, per cent

T = test temperature, °K

VMA = voids in the mineral aggregate, per cent, satisfactorily describes the effect of binder content, compaction and test temperature on fatigue resistance of the materials studied in the present work. A wider range of materials would have to be studied in order to include other significant terms in such an equation.

7. APPLICATION OF RESULTS AND FUTURE WORK

The present results reveal that a reduction in binder content below that currently specified for dense bitumen macadam roadbases and base-courses produces a marked reduction in resistance to fatigue cracking for both rounded gravel and crushed-rock aggregates. However, improved fatigue performance is obtained from better compacted materials and previous work[2] has shown that there is scope for improving compaction of dense bitumen macadam, ie reducing VMA, by at least 3 per cent in the wheelpath zones which are critical in determining the structural performance of a road pavement under traffic. There is promise therefore, that better compaction can be used to offset the lower fatigue resistance associated with lowering the binder content of dense bitumen macadam. Because of the lack of evidence of fatigue cracking of bituminous roadbases complying with current specifications the relation of laboratory fatigue testing to road performance is uncertain. In order to develop a better understanding of fatigue behaviour in practice a computer programme has been developed at TRRL to predict the fatigue lives of flexible pavements from laboratory fatigue results taking account of wheel-load distributions and variation of pavement temperature. These computer predictions will be compared with the performance of flexible pavements tested under controlled conditions of temperature and wheel load in a pilot-scale facility.

Other aspects of the role of bituminous materials in determining pavement performance require evaluation before bituminous roadbases of low binder content can be introduced with confidence. Several parameters related to structural performance of pavements with bituminous macadam roadbases are also being studied in a wider programme; these parameters include deflection of the pavement surface, resistance to deformation and complex modulus. Broader-based conclusions of the influence of mixture variables on structural performance should emerge when results of studies of these parameters have been analysed in conjunction with the fatigue performance results presented in this report.

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TABLE 1

Aggregate grading and properties of recovered binder of fatigue specimens

BS Sieve	Percent by weight of total aggregate passing BS Sieve		
	Uncrushed Branston Gravel	Crushed Croft Granite	Crushed Holcombe Limestone
38 mm	100	99	100
25 mm	90	89	91
12.7 mm	63	67	67
6.4 mm	47	51	52
3.2 mm	41	36	39
0.3 mm	18	12	10
0.075 mm	5	4.7	4.7
Properties of recovered binder			
Penetration	60	60	69.5
Ring and ball softening point	52°C	52°C	50°C

TABLE 2

Binder content, compaction and test temperature of fatigue specimens

Aggregate	Binder content (per cent by mass)	Number of roller passes	Void content (per cent)	VMA (per cent)	Test temperature (^{o}C)
Croft Granite	2.7	3	13.8	19.6	25
		9	9.3	15.1	10
		9	10.1	16.1	25
		9	8.1	14.3	35
		20	10.6	16.8	25
		40	5.8	12.6	25
	3.0	3	13.5	19.9	25
		9	11.3	17.9	25
		25	8.0	14.8	25
	4.0	3	11.3	20.0	25
		9	8.4	17.4	10
		9	8.4	17.4	35
		25	5.7	14.9	25
	5.2	3	10.2	21.4	25
		9	5.0	16.8	25
		25	2.8	14.9	25
Uncrushed Branston Gravel	2.9	3	11.5	17.7	25
		9	10.3	16.6	25
		25	7.9	14.6	25
	3.4	9	7.7	15.3	10
		9	7.9	15.5	35
		25	5.9	13.6	25
	5.0	3	3.3	14.7	25
		9	2.0	13.5	25
		25	1.2	12.9	25
Holcombe Limestone	2.4	3	14.9	20.1	25
		9	12.3	17.7	10
		9	12.3	17.7	25
		9	11.5	17.0	35
		24	8.5	14.2	25
		40	8.2	13.9	25
	3.4	3	13.9	21.4	25
		9	7.8	15.8	10
		9	8.0	16.0	25
		9	8.0	15.9	35
		24	7.8	15.7	25
		40	4.2	12.5	25
	4.6	3	8.7	19.1	25
		9	3.2	14.3	25
		24	2.7	13.8	25
		40	1.2	12.5	25

TABLE 3

Summary of fatigue test results at a test temperature of 25°C (test frequency 25 Hz)

	Bitumen per cent by mass	Number of roller passes	Mean void content (per cent)	$\varepsilon \times 10^6$ at $N = 10^4$	Mean initial stiffness (GN/m^2)
Granite aggregate	2.7	3	13.8	89	0.83
		9	10.1	74	1.18
		20	10.6	87	1.03
		40	5.8	72	2.52
	3.0	3	13.5	105	1.06
		9	11.3	86	1.04
		25	8.0	127	1.90
	4.0	3	11.3	148	0.69
		25	5.7	132	1.87
	5.2	3	10.2	171	1.48
		9	5.0	147	2.75
		25	2.8	159	2.53
Uncrushed Gravel aggregate	2.9	3	11.5	77	1.29
		9	10.3	81	1.45
		25	7.9	100	2.18
	3.4	25	5.9	76	1.77
	5.0	3	3.3	150	1.85
		9	2.0	134	1.84
		25	1.2	126	2.69
Limestone aggregate	2.4	3	14.9	105	1.25
		9	12.3	92	1.49
		24	8.5	85	2.17
		40	8.2	93	2.38
	3.4	3	13.9	161	1.46
		9	8.0	159	1.83
		24	7.8	152	2.46
		40	4.2	121	3.86
	4.6	3	8.7	196	1.46
		9	3.2	127	2.29
		24	2.7	172	2.97
		40	1.2	170	3.05

TABLE 4

Effect of variation in test temperature on fatigue results

	Bitumen per cent by mass	Test Temperature (°C)	$\varepsilon \times 10^6$ at $N = 10^4$
Granite aggregate	2.7	10 25 35	52 74 88
	4.0	10 35	128 209
Uncrushed Gravel aggregate	3.4	10 35	61 90
Limestone aggregate	2.4	10 25 35	65 92 114
	3.4	10 25 35	86 159 206

Level of compactive effort for all specimens = 9 roller passes

Test frequency = 25 Hz

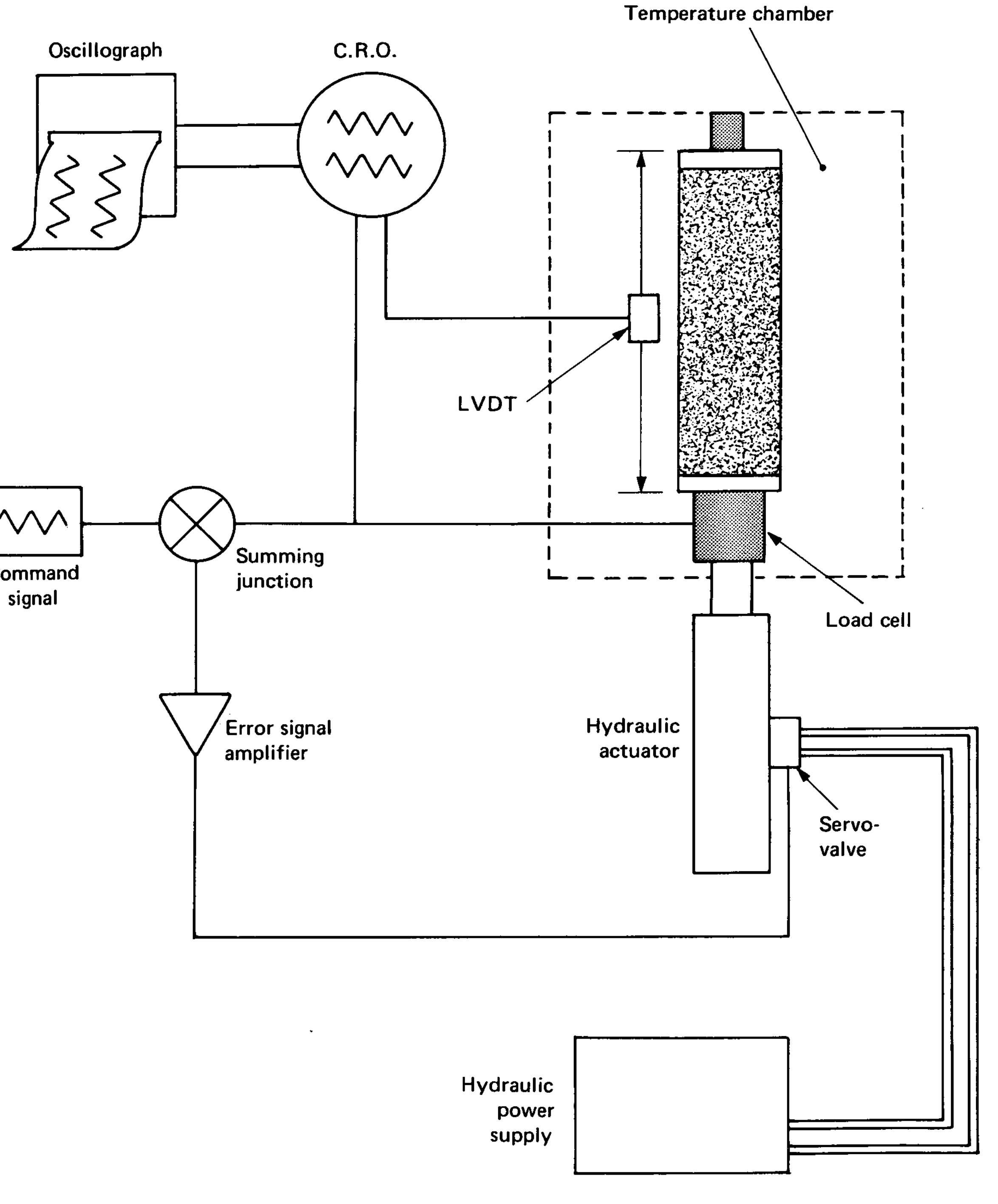


Fig. 1 SCHEMATIC REPRESENTATION OF METHOD OF TEST

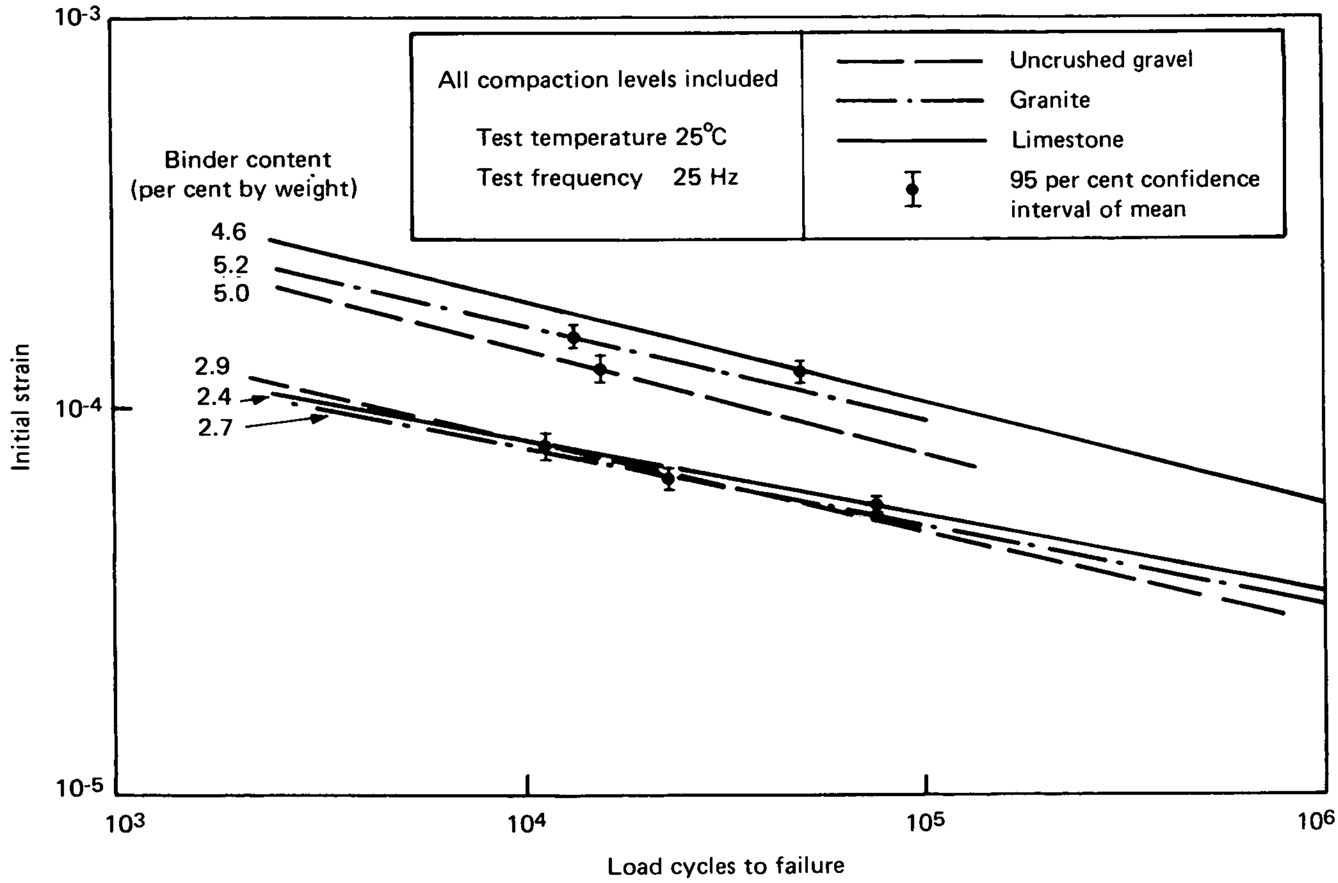


Fig. 2 EFFECT OF BINDER CONTENT ON THE RELATIONSHIP BETWEEN INITIAL STRAIN AND FATIGUE LIFE

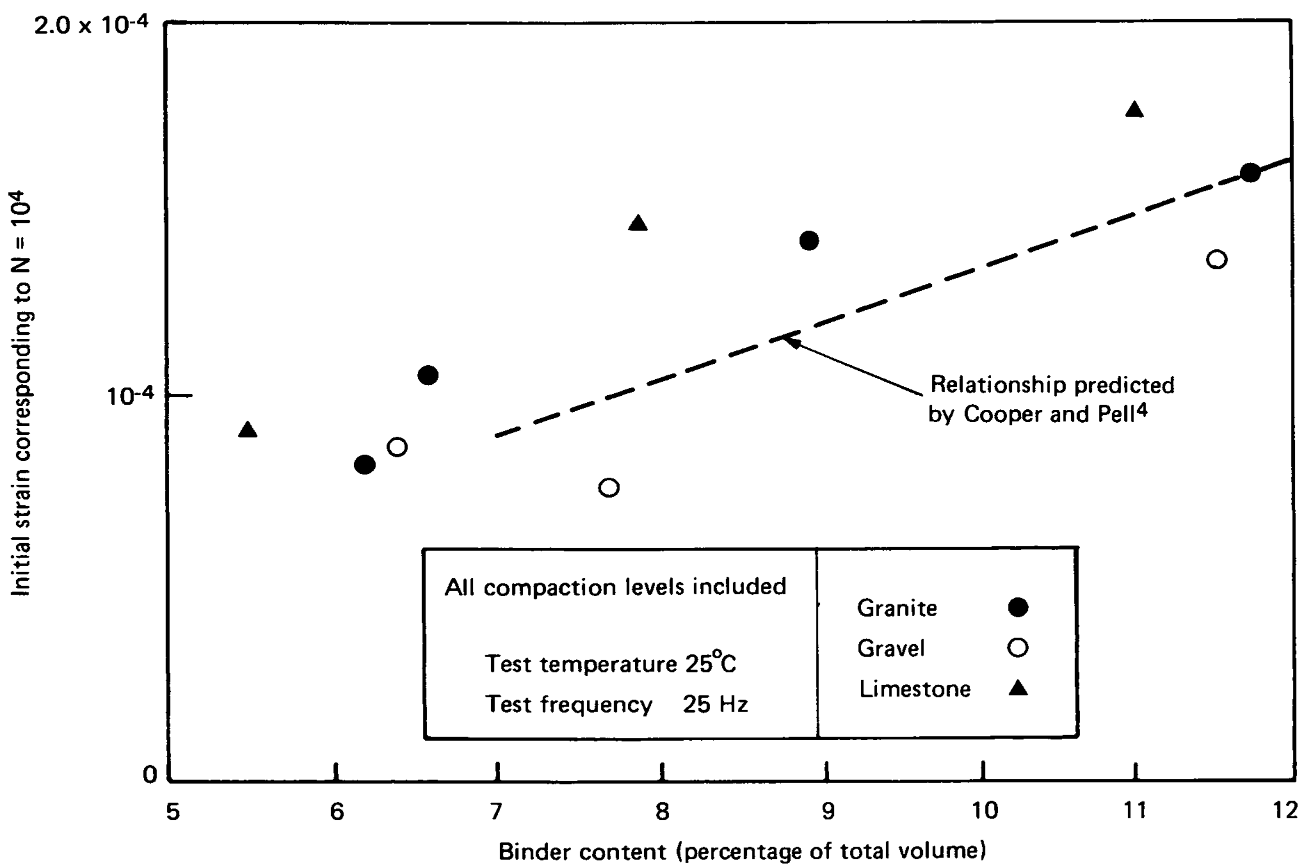


Fig. 3 EFFECT OF BINDER CONTENT ON INITIAL STRAIN CORRESPONDING TO A FATIGUE LIFE OF 10^4 LOAD REPETITIONS

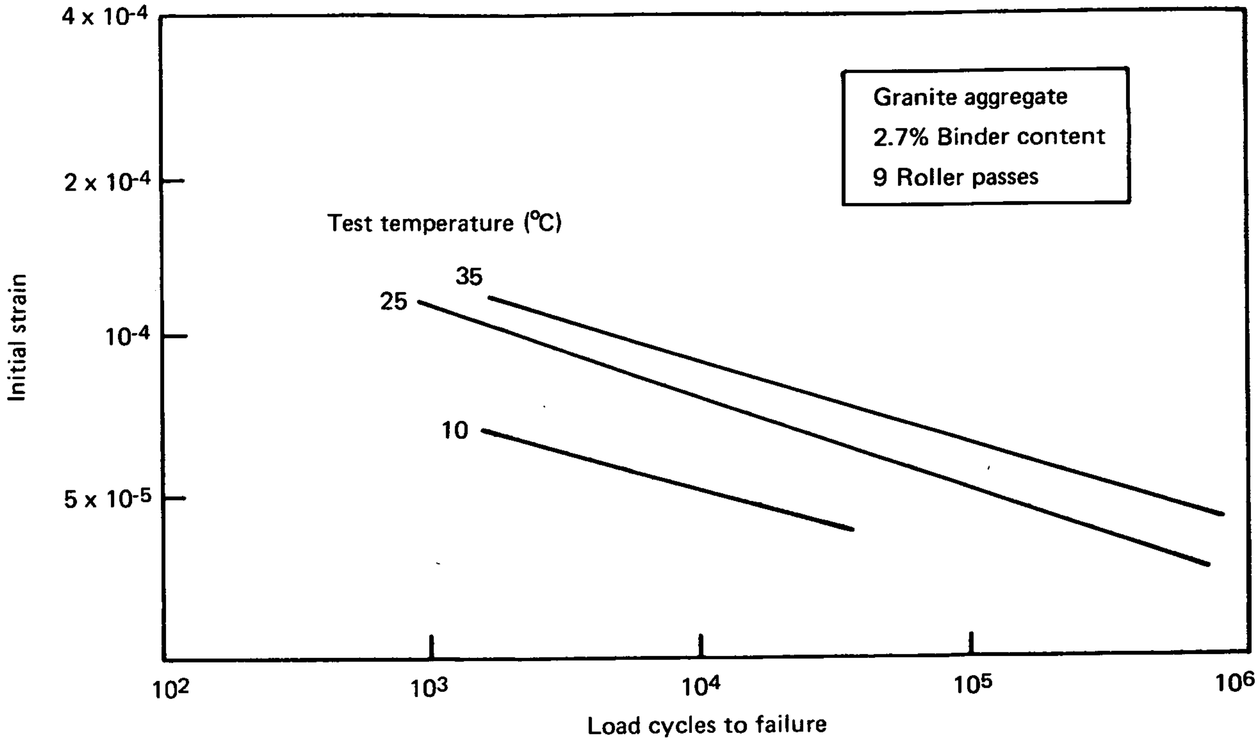


Fig. 4 RELATIONSHIP BETWEEN INITIAL STRAIN AND FATIGUE LIFE AT DIFFERENT TEST TEMPERATURES

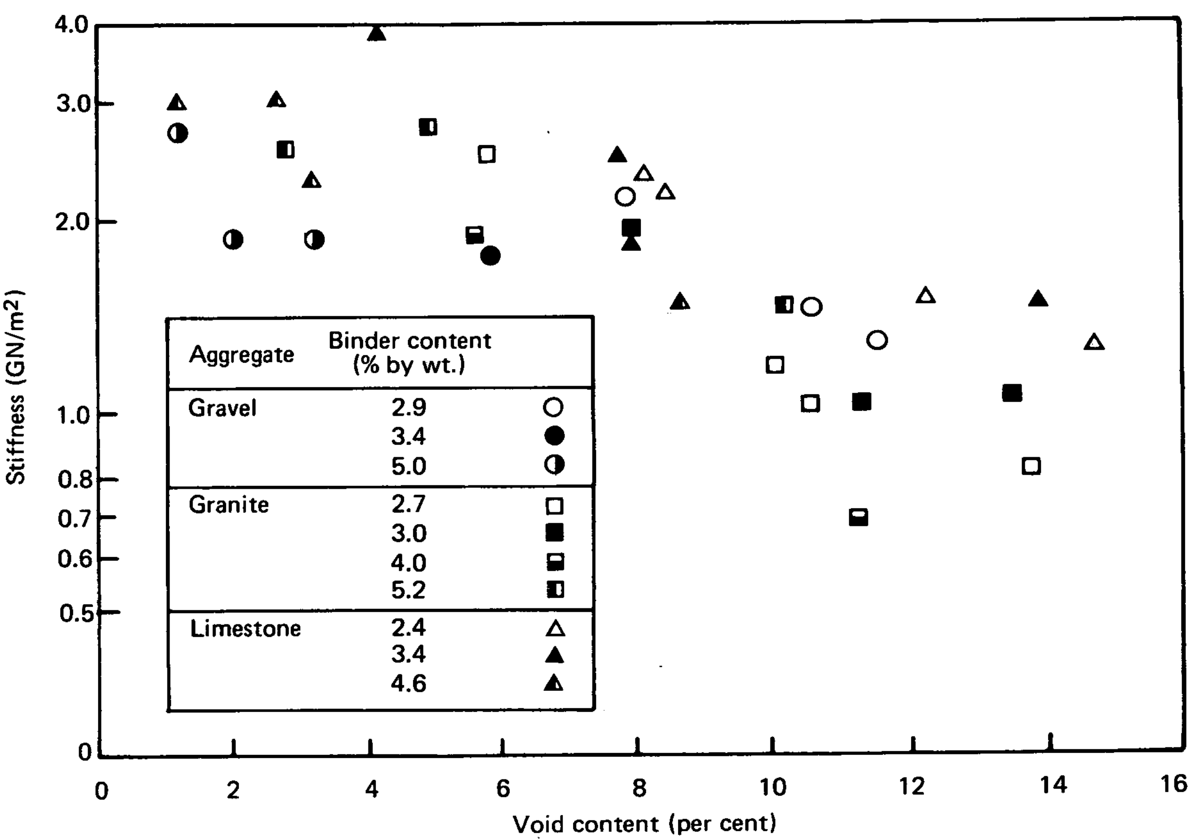


Fig. 5 VARIATION OF STIFFNESS WITH VOID CONTENT AT 25 C AND 25 Hz

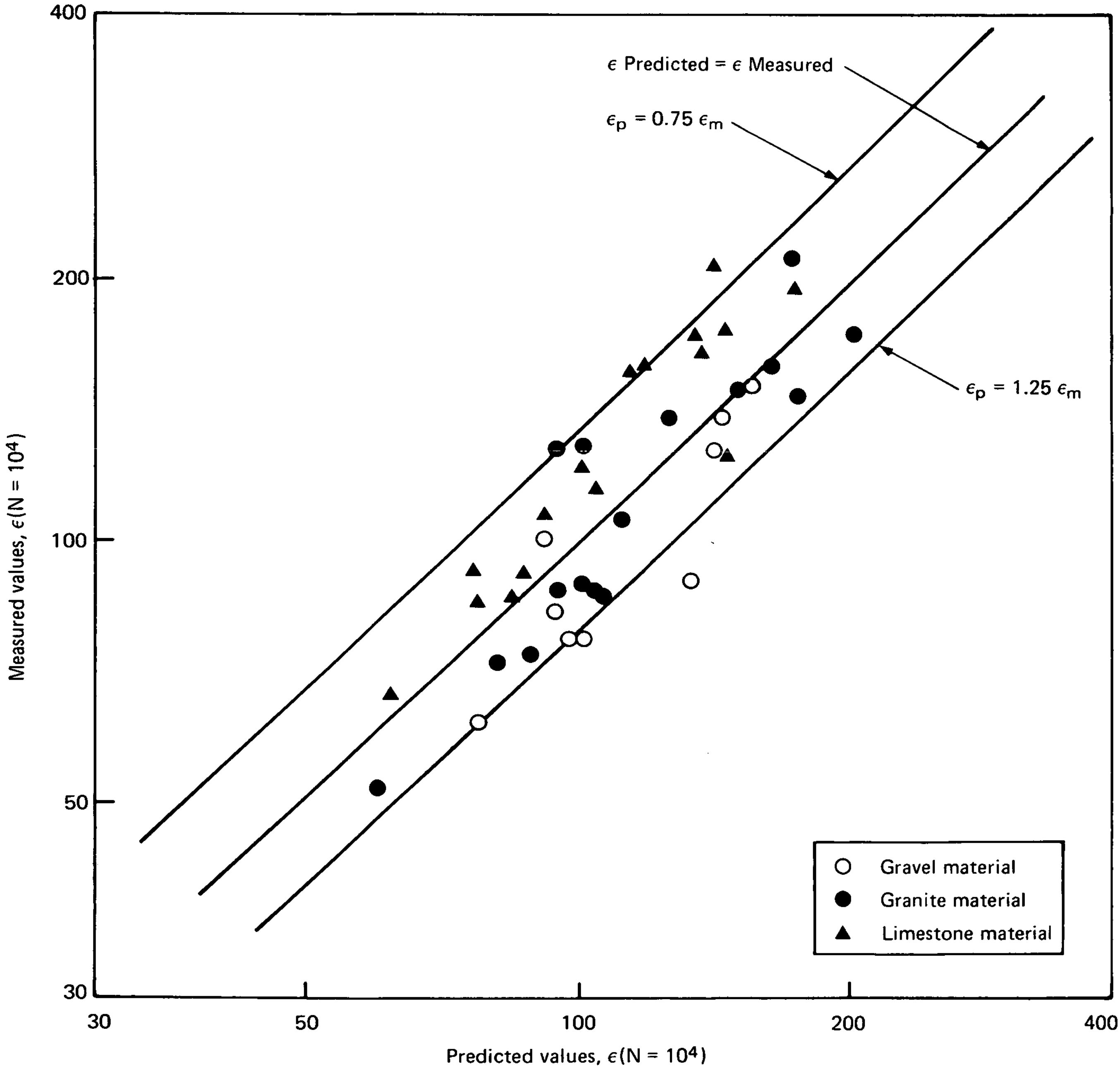
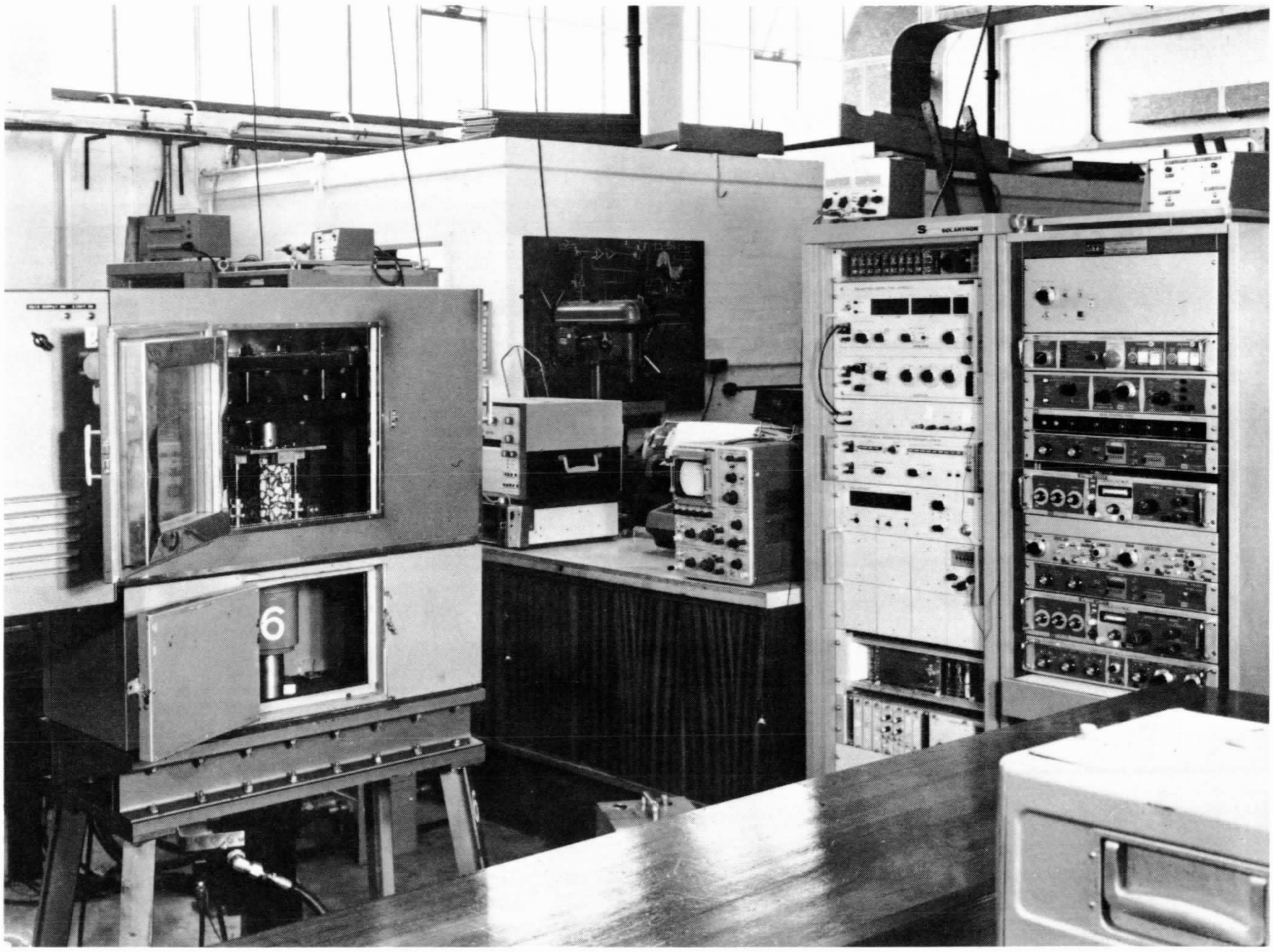


Fig. 6 COMPARISON OF MEASURED VALUES OF STRAIN $\epsilon(N = 10^4)$ WITH VALUES PREDICTED BY EQUATION 3



Neg. No. B610/72

Plate 1 TEST EQUIPMENT

(1275) Dd0536316 1,100 7/78 HPLtd So'ton G1915
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ABSTRACT

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Samples of material containing 40mm maximum size aggregate and 100 pen bitumen were cut from experimental pavements laid in a pilot-scale test facility and were loaded in direct sinusoidal tension and compression until fracture.

Although fatigue life is shown to be greater at higher test temperatures for a particular strain level this effect is far outweighed by the associated reduction in stiffness. The effect of the type of aggregate in the mixture on its fatigue resistance is small compared with that of the other factors studied. An equation relating laboratory fatigue life, binder content, compaction level and test temperature was developed using a standard multiple regression technique.

Other aspects of the role of bituminous materials in determining pavement performance require evaluation before roadbases of low binder content can be introduced with confidence. A wider programme of research is therefore being carried out to study other properties related to structural performance.

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